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THE NEW COAL AGE.[1]

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For over half a century, I have lived and moved, I have bent the knee or bowed the head—or taken the consequences—in or around coal mines. In that time I have watched the industry grow from 158,000,000 short tons, employing less than 160,000 miners in 1890, to over 600,000,000 short tons, employing 400,000 miners in 1947. It is, therefore, fitting that this presidential address should deal with coal.

But there is a far larger reason. In 1800 coal was hardly known in this country. By 1900 coal had become the source of 91⅔ percent of the country's energy, having doubled in production every ten years, almost completely replacing wood and water power for heat and power. At that time water power furnished 1⅔ percent of the country's energy. Coal production continued to grow at the same rate for another ten years, then slowed down and in 1918 reached its peak of 579 million tons. Then something happened to coal in these United States, bringing dark days for a quarter of a century. Production declined. By 1932 it was down to 310 million tons. Even in 1946, it reached only 522 million tons.

But today there are signs of blue in the sky. Coal appears to be on the threshold of a new era or, as I have called it, "a new coal age," an age in which the brightest days of the past will seem like "small business."

To understand the reason for this hope, we need to understand the reason for the dark days of the recent past. Coal has always been, at least in America, a too-low-priced commodity. The known coal fields of the United States underlie 340,000 square miles; in Illinois underlying five-eighths of the state, in Pennsylvania nearly one-third of the state. In large areas, the coal outcrops in the hillsides and one only needs a pick, shovel, and wheelbarrow to start a new coal mine. Like agriculture, it has always suffered from too much internal competition, having over 6,000 commercial companies, over 7,000 mines, and many times that number of "small mines" or "country banks." As a result, much of the time the industry has been in the red. Between 1925 and 1940 the industry is said to have had a net loss of $350,000,000. These low prices, however, gave the industry a great advantage in meeting competition from other fuels.

[1] Presidental Address, Society of Economic Geologists, Delivered at the Ottawa Meeting, Dec. 1947.

Several factors entered the picture after 1918 that materially changed conditions for coal: First, coal had always been so cheap that users thought of it as a necessary, but minor, item of expense. But, at the end of the First World War prices went for a balloon ride. People suddenly realized that coal did cost money and set about trying to save coal. As a result, electric public utilities cut their use of coal from 3.2 pounds per kilowatt hour in 1920 to 1.3 pounds in 1944. Railroad coal per 1,000 gross-ton-miles was cut from 170 pounds to 115 pounds. One railroad reported 103.2 pounds in 1946. Pig-iron-making cut coal from 3,194 to 2,629 pounds per ton of iron, and so it went. Every pound of coal saved by the consumer meant a pound less sold by the producer.

Second, prolonged strikes in the industry compelled people to turn to other fuels, which by 1918 were becoming abundant. Too often consumers, having adjusted their equipment to burning oil or gas, became "sold" on the new fuel and did not return to coal.

But the principal factor was competition with oil and gas and water power. Oil in quantity was discovered in this country in 1859. Production grew slowly because of its narrow utilization. But about 1918 there came a great expansion in its use and production. In the five years from 1918 to 1923, production increased more than in the preceding 60 years. Rich new oil fields cut sales-prices at one time to as low as six cents a barrel for "hot oil." The use of oil for house heating and a multitude of other uses just at that time played into the hands of the oil industry. Natural gas began to be used on a large scale in 1883 and the discovery of vast fields of natural gas in the southwest, which was piped to coal-using areas, cut heavily into the market for coal. Even water power took on new life at that time with the building of many large units and increased still further when T.V.A. entered the water power field. Comparing 1918 and 1946, and calling the 1918 production 100, Pennsylvania anthracite in 1946 was down to 61, bituminous coal and lignite down to 92, petroleum up to 724, natural gas to 671, water power to 508.

Obviously, the total use of energy in the United States grew rapidly in that same period, or the use of coal would have been wiped out. At the beginning of this century, the United States was using 7,500 trillion B.t.u. By 1918 it was using 22,000 trillion B.t.u. After declining to 17,500 trillion B.t.u. in 1932, it rose to 36,000 trillion in 1945. But, this increase nearly all went to oil, gas, and water power. The giant was sleeping.

But, today the outlook is changing, the giant is awakening. While between 1937 and 1945 the use of coal has dropped from 47.8 to 42.1 of the total energy used in the United States, the use of oil has risen only from 32.2 to 33.0, of water power from 3.6 to 4.2. But, the use of natural gas has risen from 10.6 to 15.7.

With the T.V.A. program nearing completion, unless the St. Lawrence sea-way project is carried out, it is doubtful if water power will increase its proportion of the total energy used in the future, if it holds its own. Petroleum seems to be about at its peak. The *known* supplies of oil are estimated at about 24 billion barrels, or about a 12-year supply. Until a few years ago, the yearly extensions of old pools and discovery of new pools kept pace with exhaustion or a little more, so that estimated proved reserves were rising.

But, in recent years, while more new pools have been discovered, the increased number has not made up for their small size. Drilling is shifting from the "more favorable" areas to "less favorable" areas, and average depth has steadily increased. A recent well went to a depth of 17,823 feet without any doubling up. All of these items increase cost and lessen the likelihood of larger oil reserves. It is said that it now costs sixty cents for each barrel of new oil discovered, as against 14 cents in 1937. Perhaps the best evidence of the tight spot oil is in can be seen in the large sums of money the oil companies and the Federal Government are now spending on research in the production of oil from coal, natural gas and oil shale.

If we assume that the general demand for energy will increase in the future as it has in the past, the demand may double in the not too distant future. It increased five times in the last fifty years. If it doubled in the next fifty years, and even though coal did not better than hold its own in the proportion of the whole, the coal industry would double its output in the next fifty years. While that may seem slow compared with doubling every ten years, it means more because it means as much increase in fifty as in the whole century before 1918. That in itself would be enough to be called a new coal age after the last thirty years of hunger and red ink.

But, that is not all. While natural gas may hold its own or even increase its ratio for some years to come, it seems unlikely that oil and water power can continue to hold their own. For a few years oil from natural gas will supplement that from the rocks, but in so doing it will cut down the gas reserves and thus hasten the day when gas too will begin to fall behind. Then, oil from coal will have to pick up the load. It is, therefore, possible to foresee not only that coal is likely to face a larger market for direct use, but have to take over an ever-increasing part of the total energy demand now supplied by oil and gas.

Oil from natural gas is or will be soon a working reality. Thus, a new gas-to-oil $15,000,000 plant now being built or built in Texas, one of several, is expected to use 64,000,000 cubic feet of natural gas a day plus 2,000 tons of oxygen and produce 5,800 barrels of hi-octane (+ 80) gasoline, 1,200 barrels of diesel oil and 150,000 pounds of alcohols. As this is only about 1/300th of the total gasoline made and used in the United States, it is clear that to make up any large deficiency in gasoline from oil would require many plants and absorb a large part of the natural gas production; thus reducing the ratio of natural gas used direct for energy and correspondingly used in direct competition with coal.

Time does not permit a lengthy discussion of oil from coal processes. Before the drilling of the Drake Well in 1859, oil made from coal had become the main source of oil for illuminating purposes. Recently the newly combined Pittsburgh-Consolidated Coal Company and the Standard Oil Development Company-Research Division of the Standard Oil Company of New Jersey began large scale research at Library, a few miles south of Pittsburgh. Results already achieved have warranted planning a $120,000,000 plant, using the Fischer-Tropsch process, outlined as follows: 1. The mined coal is crushed, dried, and heated. 2. Steam and oxygen are driven through the finely-ground coal at 2,000° F in cylindrical reactors 50 feet in diameter and 50 feet high,

yielding CO and H + (CO_2). 3. The ash is removed centrifugally. 4. The gases go to reactors where they are driven through a thick body of finely-ground catalysts where the CO and H combine to form liquid and gaseous hydro-carbons. 5. These are separated. 6. The CO_2 is separated from the gaseous portions. 7. The liquid portion is fractionated into gasoline, diesel oil, and residual oils.

A plant of that size is expected to require 20,000 tons of coal a day, 15 million gallons of water, 75 million cubic feet of oxygen (obtained by reducing 375 million cubic feet of air to minus 275° F and separating the oxygen and nitrogen). It is expected to yield 96 billion cubic feet of high B.t.u. gas in a year, 114 million gallons of gasoline, 14 million gallons of diesel oil, and fertilizers from the nitrogen.

Our concern here with this whole matter is three-fold: first, that the increasing cost and declining rate of discovery of new sources of petroleum is likely to decrease the competition of petroleum with coal, resulting in an increased demand for coal in the future; second, an increased demand for coal from which to produce oil, gas, liquid and gaseous fuels; third, that the future utilization of coal is likely to be through the medium of oil and gas and electricity, as regards both transportation and ultimate use. In other words, in the future, the energy of coal may largely go to market by pipe-line and wire, instead of by coal car and truck, and be transformed into heat, light or power at the consumer's end of the line.

There are, however, certain developments that should not be passed over unnoticed. Two of these relate to production of coal. One is experiments in burning coal in the bed recently carried on in Alabama. So far the results have not been very encouraging; but it is too early to evaluate them. Another is the vision of a machine which will, as it were, eat its way into the coal bed, crush the coal and transmit it by belt to mine cars. It has been estimated that such a machine might raise the mining rate per days from 5–6 tons per man to 100 tons. This is not as yet a reality, but research is hot on the trail. A third development is the use of a coal-gas-turbine-electric locomotive as a competitor of the diesel locomotive of today. This will soon be put to the test. The locomotive takes on coal, grinds and pulverizes it, converts it to gas, frees it of ash, derives power from it by a gas turbine. It has been estimated that the fuel cost of operating such a locomotive would be about $20,700 a year against a fuel cost of $51,000 for a diesel locomotive. This is of interest not alone for rail transportation, but for future stationary power production as it requires no water. Now large power plants must have a liberal water supply.

All that has gone before is simply introductory to the real purpose of this paper, an inquiry into the adequacy of our coal reserves to meet such a demand as is here envisioned. During the last few years the writer has had occasion to reëstimate the coal reserves in several areas, with results that have led him to question the very large figures arrived at by M. R. Campbell in the early part of this century. The only estimate that has been available is one made by M. R. Campbell in 1913. This estimate appeared to give the United States more than half of the world's supply, and furnished the basis for statements that have appeared and been widely used that this country had enough coal to

last 6,000 years. Campbell's estimate, which reached 3,225,394,300,000 metric tons, was for all of the coal in the bed, a fact sometimes overlooked in some recent criticisms of his figures. It also takes account of all coal down to 14 inches and to a depth of 3,000 feet. More recent estimates are likely to take account of only the "recoverable coal," based usually on 1,000 tons recovery per acre-foot of bed, and with a thicker minimum, especially for the lower-rank coals. Yet with these differences, the Campbell estimates have been under heavy fire as being too high. One mining engineer has suggested that they are at least ten times too high. A recent resurvey of Canada's coal reserves by Dr. B. R. Mackay reduced their 1913 figure from 456 billion net tons of "actual" reserves and 882 billion net tons of "probable" reserves, a total of 1,338 billion net tons, to 99 billion net tons of "minable" and 49 billion net tons of "recoverable" coal, a total of 148 billion net tons, a cut of 89 percent.

At once we face the lack of any accepted standard in computing reserves, or of designations for different types of reserves. Simply as something at which to throw stones while waiting for some agreement to be reached, I offer the following: (We are not here concerned with value or price, but only with tonnage. Coal that may not be minable with profit today may be recoverable by methods of mining or recovery not in use today, such as by burning in the ground, or the use of new types of machinery or mine layout.)

First is the matter of resources versus reserves. The dictionary definition of reserves is "held back" for future use. To me, resources mean, immediately available—money in pocket or bank, our standing army, navy, and air power, our available mining or milling capacity, our available farm land, the football men in the field, etc.; reserves, money we can obtain by negotiation, our army and other "reserves" that can be "called into service," undeveloped mineral resources, requiring the opening of new mines or the building of new mills, farm land that can be obtained by cutting down timber, football men now on the sidelines, etc. I would, therefore, define reserves as undeveloped resources. That is, for coal, coal of lesser thickness, greater depth or other factors beyond those now being mined commercially with financial success.

Second, I would distinguish the reserves as "known or probable," and "possible." As a rule coal beds are more persistent over larger areas than oil or gas or metalliferous deposits, though not as persistent as many kinds of rock deposits. I believe, therefore, that the area of "known" or "probable" coal around a point of measurement or "datum point" may be much larger than allowed for oil, gas, or metalliferous deposits.

At the same time, we must recognize that different coal beds differ greatly in regularity and that account should be taken of that fact. To do that I propose the use of a "factor of regularity," to consist of the reciprocal of the sum of the differences between each measurement of a coal bed and the average in any area in question, divided by the sum of the totals of the several measurements. Thus, suppose the total of all measurements for each of two beds in an area add up to 100 feet. Suppose the average measurement in each instance is 6 feet. In one bed the sum of the differences between the average and the thicknesses of the several beds is only 8 feet, indicating a very regular bed; the factor of regularity would be 92 per cent. If the same sum for the other bed were 36 feet, indicating an irregular bed, the factor would be 64 percent.

In the first bed an average thickness of 5.5 feet is safe; in the second bed 3.8 feet would be a safer figure. Or, if the area of measurements was ten miles wide, the area outside the area of measurements might safely be extended to 9.2 miles for the first bed, but only to 6.4 miles for the second bed. This practice was followed by the Coal Board of the U. S. Geological Survey in valuing coal on public lands from 1913 to 1920, when the sale of public coal lands was stopped.

The writer has recently had occasion to reëstimate the coal in several areas that would seem to substantiate these criticisms.

Recently (1946–1948), the writer reëstimated the coal in the Colorado part of the Uinta Coal Basin (Colorado–Utah). Campbell's figures were as follows (1913) (Bituminous Coal only):

Depth	Area		Coal (1,000's of tons)	
	Sq. mi.	Acres	Metric tons	Net tons
Less than 3,000 ft.	2,780	1,780,000	75,847,500	83,432,250
3,000–6,000 ft.	3,720	2,380,000	130,000,000	143,000,000
Total.....	6,500	4,160,000	205,847,500	226,432,250

In comparing these figures with later estimates, it must be emphasized that these figures cover all of the coal 14 inches or more thick within the depth limits given. Whereas the writer's figures, arrived at in computing the present-day value of certain of these lands, confined the tonnage to coal equivalent to coal now being mined in the basin or near-by. A minimum thickness of 3 feet was used and maximum depth below point of ingress of 1,000 feet was used (regardless of depth below surface) and a recovery of only 1,000 tons per acre-foot was used. Moreover, actual mining practice in the field was followed in which, for example, a bed varying from 9 to 25 feet was treated as a 9-foot bed, because only 9 feet of the bed are being recovered; or, where two beds each of minable thickness, but too close together to mine separately or too far apart to mine together, are treated as one bed, having the thickness of the thicker bed.

Had the same restrictions been used in the original estimate, it is now estimated that the figure of 83,432,250,000 net tons would have been reduced to 16,020,000,000 net tons, or about one-fifth of Campbell's figures. Or, if 10 percent be allowed for coal between 14 inches and 3 feet and for beds thrown out for technologic and economic reasons, and 1,830 tons per acre-foot, instead of 1,000 tons per acre-foot, were used, the total would be 32,278,260,000 tons, which is 38 percent of Campbell's figures. If this single example were typical, we might say roughly that Campbell's figures were three times too high, even for the full original deposit.

But, the writer recently reëstimated the bituminous coal resources of Pennsylvania.[2] Campbell's figures as of 1917 were: bituminous coal, 102,-

[2] Pennsylvania's Mineral Heritage, Penna. Dept. of Internal Affairs, 1944, pp. 79–85.

502,084,000 net tons; semi-bituminous, 10,002,270,200; total, 112,504,354,200 net tons. In 1921–1926, J. F. Reese and J. D. Sisler reëstimated the State's bituminous coal resources, using all the then available data, mapping each bed, using isopachs and the planimeter for areas. They used a minimum thickness of 18 inches. They obtained: original deposit, 75,093,459,000 net tons (to be compared with the figures above); mined out and lost, 5,823,163,000 net tons; recoverable, 44,022,840,000 net tons. If the coal mined out and lost in the 13 years, 1913 to 1926, were added, the figure would have been about 46 billion tons of recoverable coal, as against Campbell's 112.5 billion tons of original coal, about 40 percent.

Between 1921 and 1944 some additional detailed field work in the coal fields permitted rechecking the 1921–1926 figures. The net result was to boost materially the original deposit and give a higher recovery figure, if, as was done, account was taken of coal down to one foot thick. The latest figures showed:

Original deposit	84,616 millions of net tons
Mined out and lost	9,589 millions of net tons
Resources, over 3 feet	13,430 millions of net tons
Resources, 2–3 feet	15,562 millions of net tons
Reserves, 1–2 feet	23,401 millions of net tons
Total resources and reserves	52,393 millions of net tons

If we consider only coal over 2 feet thick as workable today, we should have only 28,922, say, 29 billions of tons against Campbell's 112.5 billions of tons, or not far from one-fourth.

If these two examples are fairly typical, one of the east and one of the west, it might be roughly estimated that for practical purposes Campbell's figures should be reduced to one-fourth east of the 100th meridian and to one-fifth west of that meridian.

But, as I have suggested, if our future use of coal is to be by way of pipe or wire and the electric motor (our Diesels are really electric locomotives), we must consider the B.t.u. rather than the pound as our measure. On the basis of this very limited study, the following figures are given:

TABLE.

REVISED ESTIMATE OF THE UNITED STATES COAL RESOURCES.
(in millions of net tons.)

Rank	Original deposit		Recoverable coal	Energy equivalent	
	Campbell	Ashley		Factor	Net tons
Bituminous					
Appalachian	550	450	137.5	1.00	137.5
Central	528	396	132.0	.85	112.2
Western	415	138	83.0	.81	67.2
Subbituminous	946	315	189.0	.75	141.7
Lignite	1,086	362	217.0	.60	130.2
Total	3,525	1,661	758.5		588.8

These figures are presented, not as having any authority, but as possibly more realistic than those now so widely quoted.

One more question remains. Will atomic power soon render this whole discussion obsolete? I think not, at least soon. To engineers "power" means energy *under human control* and available for doing mechanical work. Energy involves mass and velocity. It is measured by one-half the mass times the velocity squared. A small mass at high speed may have as much energy as a large mass at low speed. When, however, the speed leaves the speeds with which we are familiar and rises into the thousands of miles per second, a very small mass acquires a tremendous energy, but at the same time becomes more difficult of *human control*.

There is no question as to the reality and value of atomic energy for atomic bombs. It may even find other uses in engineering work or in jet planes; wherever an explosive is needed. Radio-active substances already have many uses in medical and engineering work and these uses will probably multiply. But, as a source of power to replace coal, I see no challenge to coal unless one or all of three things take place: 1. The discovery of new and vast deposits of uranium or thorium ores, relative to those now known. 2. The discovery of a *cheap* method of concentrating the uranium compounds *disseminated* throughout many of the rocks. 3. The power obtained in splitting the atom might be compared to the sparks obtained in sawing an iron rod in two. If, however, a process of converting matter directly into energy should be discovered, the whole picture would change. But, in the meanwhile, coal will be king.

HARRISBURG, PA.,
November 12, 1948.

MONZONITE INTRUSION AND MINERALIZATION IN THE COEUR D'ALENE DISTRICT, IDAHO.[1]

ALFRED L. ANDERSON.

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ABSTRACT.

In the Coeur d'Alene district of northern Idaho, the conversion of diorite to monzonite and syenite through endomorphic processes, the development of zones of extensively bleached (sericitized) rock, and the metallization seem to be closely related phenomena and associated with the work of potash-rich solutions emitted from a deep magmatic source. In the beginning some of the magma was intruded locally to high levels and there consolidated as hornblende-pyroxene diorite, but the potash-rich solutions that followed the intrusion soaked upward through the still hot crystalline rock and introduced into it large quantities of potash feldspar (chiefly microcline), considerable amounts of albite, sphene, and magnetite, and lesser amounts of other minerals. As a result of these additions the originally consolidated diorite was changed to rock of monzonitic and syenitic composition. In places the bordering sedimentary rock (Belt series) was "granitized" by the intruding magma and the potash-rich solutions.

Elsewhere the potash-bearing solutions were directed along zones of faulting in the sedimentary rocks where the cooler environment favored the formation of sericite rather than the higher-temperature feldspars. As a result, zones of extensively bleached (sericitized) rock came into existence.

Structural adjustments along the zones of bleached rock and locally along the borders of the monzonitic rocks then provided openings for the movement of ore-bearing solutions with development of replacement veins in the bleached rocks and contact metamorphic deposits adjacent to intrusive rocks.

[1] Presented before the Geological Society of America, New York Meeting, Nov. 1948.

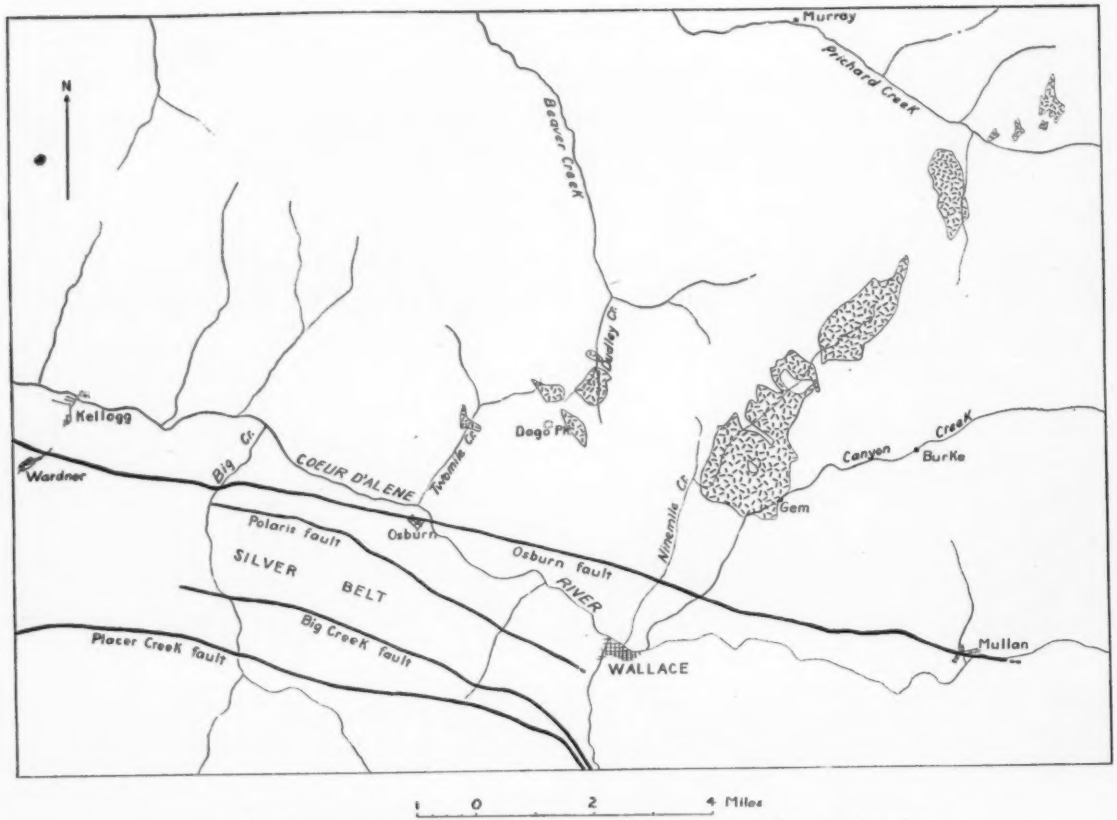


FIG. 1. Index map of a part of the Coeur d'Alene district, Idaho, showing the distribution of the monzonitic rocks and the location of the Silver Belt.

The potash introduced into the solidified but still hot igneous rock and into the sedimentary rock along the zones of faulting presumably evolved as a differentiation product of the deep source magma. Formation of potash-rich solutions at the magmatic source appears to be a prerequisite for mineralization in the Coeur d'Alene as in many other mining districts.

INTRODUCTION.

AMONG the outstanding geologic features of the Coeur d'Alene district of northern Idaho are the intrusive monzonites, the zones of extensively bleached (sericitized) rock, and the ore deposits. Much has been written on the ore deposits and in late years on the zones of bleached rock,[2] but nothing pertinent has been added to our knowledge of the monzonitic rocks since their early petrographic descriptions by Calkins.[3] Although the monzonitic rocks have generally been recognized as the "ore bringers," no attempt previously has been made to define their more exact role in the mineralization process or even to present the story of their own complicated development.

The writer has worked on the problem of the monzonites periodically since 1927 and has found that the rocks possess a complicated genetic history in which endomorphic processes have played a very important role. Still broader studies have led to the conclusion that a close relationship exists between the endomorphism, the development of the zones of extensively bleached (sericitized) rock, and the mineralization. All three phenomena are apparently closely associated with the work of potash-rich solutions from a deep magmatic source which supplied the potash feldspar that converted earlier consolidated diorite to monzonite and syenite, the sericite that produced the zones of extensively bleached rock, and the necessary environmental conditions for the metallization.

MONZONITIC ROCKS.

Distribution.—The monzonitic rocks, as shown in Fig. 1, are in two groups of seven and five bodies respectively. The larger and more numerous bodies are elongate in a belt of decreasing width that extends north-northeast from Gem for a distance of about 9¼ miles. The other bodies are grouped in the vicinity of Dago Peak in the upper drainage basins of Dudley and Twomile Creeks, about 3 to 4 miles northwest of the lower end of the main belt .

These intrusives invade all members of the Belt series (Precambrian), except the Striped Peak, and reach their greatest development in the Prichard and Burke.[4]

Most of the study has been confined to the largest body at the southwest end of the main belt and to the smaller bodies in the vicinity of Dago Peak.

[2] Shenon, P. J., and McConnel, R. H., The Silver Belt of the Coeur d'Alene district, Idaho: Idaho Bur. Mines and Geology Pamph. No. 50, 1939.

Sorenson, R. E., Deep discoveries intensify Coeur d'Alene activities: Eng. and Min. Jour., vol. 148, No. 10, pp. 70–78, 1947; Silver Summit opens rich ore: Eng. and Min. Jour., vol. 149, No. 7, pp. 70–73, 151, 1948.

[3] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, pp. 44–48, 1908.

[4] U. S. Geol. Survey Prof. Paper 62, op. cit., Pl. I.

distribution of the monzonitic rocks and the location of the Silver Belt.

Varieties.—Although mapped as monzonites, the bodies vary widely in compositional and textural characteristics and show every gradation from diorite to syenite and from a coarse-grained, somewhat porphyritic rock to one that is medium- to very coarse-grained and in part strikingly porphyritic. In general the smaller bodies are more calcic than the larger and show transitions from monzonite to diorite. Except at margins, the larger bodies tend to be more coarsely crystalline and to have a composition more nearly that of syenite. Marginal zones are generally somewhat finer grained and a little more calcic with transitions from monzonite to diorite, but there are local exceptions. In the marginal part of the large stock near Gem the rock shows intricate and commonly abrupt transitions from dark, medium-grained diorite and syenite to conspicuously light-colored, coarsely and in part strikingly porphyritic syenite.

Description.—The rock that composes the larger bodies is mostly light gray, moderately coarse, and more or less conspicuously porphyritic. It contains a preponderance of feldspars including variable amounts of white, often striated plagioclase and gray-to flesh-colored perthitic microcline, also fairly numerous grains of greenish-black hornblende, and minor but in part conspicuous grains of sphene and epidote and less conspicuous ones of pyroxene and quartz. Minerals other than these cannot generally be recognized without the microscope. Much of the plagioclase and potash feldspar are in grains of about the same size, but some of the grains of potash feldspar attain lengths of a centimeter or more and give the rock its somewhat porphyritic character. Such grains usually show prominent carsbad twinning. Unless the phenocrysts are particularly numerous, there is no safe way to estimate the proportions of plagioclase and potash feldspar without the microscope and hence to tell on casual examination whether the rock should be classed as monzonite or syenite.

In the smaller bodies near Dago Peak the rock tends to be darker, medium rather than coarse grained, and granular rather than porphyritic, but transitions into coarser and also into conspicuously porphyritic facies do occur.

Some of the marginal rock, however, has a remarkably different appearance, particularly the peculiar light and dark syenitic rock on lower Ninemile and Canyon Creeks. A part of the rock is coarsely porphyritic and has tabular crystals of potassic feldspar as much as 2 inches long in roughly parallel arrangement embedded in rather dark, granular, medium-grained matrices of greenish-black hornblende, lighter-colored pyroxene, feldspar, and usually sphene. In some of the rock the large oblong crystals are rather widely scattered through the dark-colored matrix, but such rock may shade abruptly into rock composed of about half feldspar phenocrysts and half matrix and on into rock composed almost entirely of the phenocrysts. The highly feldspathic rock, because of the roughly parallel arrangement of the crystals, has a coarse trachytic appearance.

Mineralogic Characters.—Despite the wide range in composition and the marked contrasts in general appearance, the various rocks contain the same minerals which differ only in proportions and not in kind and relationships. In addition to the minerals already mentioned—the perthitic microcline, plagio-

clase, hornblende, pyroxene, epidote, sphene, and quartz—the rocks also contain variable but generally small amounts of orthoclase, albite, biotite, actinolite, apatite, allanite, zircon, garnet, magnetite, chlorite, zoisite, sericite, and pyrite. Some of the minerals show the interlocking relationships characteristic of consolidated igneous rocks (Figs. 2–4), but others possess intricate penetrating and penetrated relationships (Figs. 6–11) not generally associated with normally consolidated rock.

Pyroxene occurs rather sparingly through the prevailing rock of the larger bodies and somewhat more abundantly in marginal zones and in the smaller bodies. It is a weakly pleochroic sodic variety of light green color and monoclinic crystallization. Many of its grains are mantled by hornblende, and some are no more than small irregular cores within the hornblende crystals. Otherwise the pyroxene is largely altered to fibrous actinolite or to epidote and chlorite.

Hornblende, which composes about 10 percent of the prevailing rock in the larger bodies and even more of the rock in the marginal zones and smaller bodies, is green in thin section with pronounced greenish-yellow to bluish-green pleochroic colors. It tends to form well-shaped, commonly twinned crystals, many of which are enclosed poikilitically within the large grains of potash feldspar (Fig. 5), in part as small irregular remnants (Fig. 9). Many of the crystals have ragged edges and some are bordered and penetrated by irregular fringes of acicular, pale-greenish actinolite, and also by such accessory minerals as sphene, apatite, magnetite, and biotite. Its occurrence as mantles on the pyroxene has already been noted. Except for the actinolitic development, the hornblende is generally little altered but locally may be partly changed to epidote and chlorite.

Plagioclase is the most abundant mineral of the dioritic rocks and a subordinate one in the syenitic. Its character is much the same regardless of the type of rock in which it occurs. It appears to be somewhat more calcic in marginal zones and in the smaller bodies than in the more central parts of the larger bodies. All of it is highly zoned and the central, more calcic zone is generally saussuritized (Figs. 2–3), more so in the more calcic than in the less calcic rock. A few of the plagioclase grains show oscillatory zoning, and the highly altered calcic zones then alternate with the intervening little altered, less calcic zones. In general the innermost zones are too decomposed for precise determination, but clear, unaltered remnants in some of the cores indicate that the original composition was at least an andesine and in some cases probably labradorite. Most of the altered cores are rimmed by clear striated plagioclase (Figs. 2–3) with extinction angles and indices of oligoclase (averaging An_{15} to An_{20}), but some of the zoned crystals are mantled by albite.

The crystals generally show a tabular euhedral and subhedral development, but many, especially in the more alkalic rock, are irregularly indented (Figs. 6–10) and even veined by bordering grains of potash feldspar. Much plagioclase also occurs as irregular remnant grains within the potash feldspars (Fig. 7) with detached parts as oriented islands (Fig. 11). In places only shadowy outlines of the plagioclase crystals remain. Like the hornblende its

grains are commonly penetrated by the accessory minerals and many of them also by grains and veinlets of epidote. Some are also swept by aggregates of sericitic mica.

Orthoclase is a sparsely distributed mineral in most of the rocks and is always subordinate to the microcline. It forms small, wedge-shaped, straight-edged grains between the plagioclase crystals, as well as large, better-formed grains of phenocrystic size. The former have the outlines determined by the borders of the plagioclase and hornblende crystals, but the larger tend to assume their own crystal outline by penetrating into and through bordering plagioclase or hornblende crystals. Such crystals, therefore, have minutely irregular borders and commonly hold island-remnants of the plagioclase grains (Fig. 8) and the hornblende (Fig. 9). This type of orthoclase seems to be more abundant than that which merely fills in between the plagioclase crystals. Some of the larger grains appear to have been built on the smaller grains, for in places there is a gradational extinction outward from a sharply bordered inner core, which suggests addition of orthoclase of slightly different sodic content.

The phenocrystic orthoclase, however, has generally not retained its near-crystal outline, but as shown in Figs. 8 and 9, is deeply penetrated by microcline and even broken up into island-like inclusions without any disturbance of the crystal orientation. In contrast to the plagioclase, the orthoclase is remarkably free of secondary products.

Microcline, the most pertinent of the rock minerals, has many interesting characters. Its grains, whether present as phenocrysts or as a part of the matrix, show a pronounced tendency for tabular, euhedral development, but like the orthoclase, the boundaries are actually minutely irregular. Most of the grains are perthitic (Figs. 4–6, 8–18) and the extent of perthitic development seems to reflect the quantity of microcline in the rock. In the dioritic facies the microcline is generally only slightly perthitic, if at all, whereas in the syenitic rock it is ordinarily highly perthitic. The perthitic development generally extends rather uniformly through the microcline grains, but in some of the larger crystals in the monzonitic and dioritic zones the perthite is confined to marginal parts of the crystals and does not reach the centers. The perthitic patterns are quite variable, but are in part controlled by crystallographic directions of the host. If not too perthitic, the microcline shows its characteristic plaid structure, which otherwise is obscure. The perthite apparently has in large part resulted from the introduction of albite into the microcline, mostly as irregular, replacing veinlets.

Some of the microcline crystals have another notable feature; namely, a striking oscillatory zoning (Figs. 11–13). In some the zonary banding may be due to shadowy preservation of zonal bands of replaced plagioclase crystals (Fig. 11), in others to oscillations in the proportions of soda and potash in successive shells (Fig. 12), and in still others to preferential development of perthitic albite in bands parallel to crystallographic boundaries (Fig. 13).

Relations of the microcline to other minerals are especially noteworthy. As pointed out earlier, the crystals of microcline extend irregularly into the bordering grains of plagioclase (Fig. 6) and orthoclase (Figs. 8–9) and even

through them (Figs. 8, 11). Such grains are usually more or less completely filled with inclusions of the bordering mineral grains, either as remnant, oriented islands (Figs. 8, 11) or as remnant grains of diverse orientation (Figs. 7, 12). Some of the larger grains may even hold mineral aggregates representing rock of dioritic composition, apparently as remnants of what were once much larger bodies (Figs. 4–5). As explained later, these relationships are interpreted as evidence of replacement, and from the abundance of remnants, in many cases only as shadowy outlines, it is apparent that the microcline has made way for itself largely, if not wholly by replacing the orthoclase, plagioclase, and hornblende.

Like the orthoclase and unlike the plagioclase, the microcline is strikingly free of alteration products.

Albite has a much more restricted distribution than the other minerals and is largely confined to the rock exceptionally rich in microcline. It is most abundant in the peculiar porphyritic syenites near the southwest end of the stock near Gem, and it is invariably associated with microcline that is more than ordinarily perthitic.

Excluding that which apparently entered the microcline as perthite and that which may have been added as mantles to plagioclase, the albite forms narrow seams or rims along the borders of the microcline grains (Figs. 14–15) and here and there veinlets or stringers directed along fractures in the microcline (Fig. 17). Normally the grains in the seams and veinlets are small, but locally the grains increase in size and penetrate deeply into the microcline and virtually usurp its place (Fig. 16).

The close association of the albite with the perthitic microcline deserves further comment. The rims and veinlets appear only where the microcline is highly perthitic and are lacking where conditions are otherwise. Curiously, as shown in Fig. 17, the veinlets and stringers of albite cut the perthitic intergrowths; yet, as explained later, the perthitic development and the rimming are probably the products of continuing albite deposition.

Like the potash feldspars, the albite is conspicuously free of alteration products.

Quartz generally constitutes less than 5 percent of the rock and occurs mostly as wedge-shaped grains between the feldspar crystals or as lobate grains penetrating them. In some places it also occurs as occasional small remnant grains in the feldspars and hornblende.

Biotite is seldom visible, even in thin section. Occasional small grains have been noted locally between crystals of perthitic microcline and as irregular grains penetrating the margins of some of the hornblende crystals. Most of that seen was largely altered to epidote and chlorite.

Sphene is exceptionally abundant, forming perhaps as much as 2 percent of the rock constituents, and may be observed as brownish grains without a lens. It appears in thin section as lance-shaped, usually twinned crystals which penetrate hornblende and feldspars from grain contacts. Its crystals show some tendency to occur in clusters, generally along grain contacts of the feldspars and hornblende and especially near grains of lobate quartz. Most

crystals are without inclusions, but some have been found with oriented remnants of microcline (Fig. 18) and with small engulfed grains of magnetite

Apatite is another relatively abundant accessory mineral and forms fairly large and long crystals of hexagonal cross section, mostly concentrated along the boundaries of the various feldspar grains and the hornblende, especially near grains of lobate quartz.

Magnetite is also a common and rather abundant accessory mineral and forms small to large grains, which, like the sphene and apatite, show a preference for grain boundaries and a more or less close association with quartz. It occurs in the hornblende as well as in the various feldspars, and has been found with rims of sphene and epidote. It is more sporadically distributed than the other accessory minerals and some of the included grains apparently have little relation to boundaries of the host mineral.

Garnet forms yellow-brown grains in some of the rock of the main body near Gem. Its grains are mostly concentrated along albite seams and commonly contain included remnants of hornblende, biotite, microcline, and albite.

Zircon is a minor rock constituent and is confined to occasional small crystals along grain boundaries and along cleavages within the feldspars and hornblende.

Epidote is a notably conspicuous mineral, commonly as grains visible to the unaided eye, and ordinarily comprises several per cent of the rock constituents. Its occurrence as an alteration product of hornblende and biotite has already been mentioned. It also forms large irregular grains in the plagioclase and locally small irregular veinlets in the microcline. Mantles of epidote about crystals of magnetite, sphene, and allanite are not uncommon.

Allanite occurs sparingly as reddish-brown, weakly pleochroic crystals along or near grain boundaries of the feldspars and some of the other minerals. Its crystals are generally twinned and are well shaped, except for local indentations by quartz.

Pyrite occurs in some of the rock cut by seams of carbonates. Its crystals are small and irregularly distributed and are generally mixed with the grains of magnetite, either as separate individuals or as borders on and veins in the magnetite.

Other minerals such as *actinolite, chlorite, zoisite,* and *sericite* have already received incidental mention. The actinolite appears sporadically as irregular fringes on hornblende crystals and as needles and aggregates of needles penetrating hornblende, pyroxene, and plagioclase. Chlorite is a common alteration product of hornblende and biotite; zoisite, a minor alteration product of plagioclase but occurring relatively abundantly with sericite in saussuritized cores of plagioclase crystals. Sericite also occurs rather commonly as aggregate patches in less saussuritized plagioclase grains and to limited extent as grains in the other feldspars.

Paragenesis.—The minerals in the monzonitic rocks have either the interlocking relationships characteristic of normally crystallized magma or the penetrating and engulfing relationships indicative of replacement of rock already consolidated. A few minerals have features of both.

Those minerals with the interlocking euhedral, subhedral, and anhedral relationships of normal magmatic crystallization include the pyroxene, hornblende, plagioclase, a part of the orthoclase, biotite, and quartz, and perhaps a part of the accessories. That the pyroxene belongs here is indicated by its unimpeded crystal development and by its mantles of hornblende, a relationship that points to reaction between crystals and magma during consolidation stages. The magmatic crystallization of the hornblende is also indicated by the usual perfection of its isolated crystals, unless penetrated by actinolite and the potash feldspars, and by evidence of mutual interference during growth where grains are closely crowded. Its mantling relations indicate that it formed later than the pyroxene and its good outlines in general suggest that such of it crystallized ahead of the plagioclase with some overlapping on the plagioclase. The latter mineral with its highly zoned euhedral and subhedral crystals (Fig. 2) reflect magmatic crystallization under conditions of fairly rapid cooling.

The other minerals regarded as magmatic reappear as members of the other group of additive minerals. Some of the sparsely distributed grains of biotite at hornblende margins may be a reaction product between the hornblende and the magma, and the occasional remnants within the potash feldspars may have been deposited from the magma, but most of the biotite apparently replaces and therefore was added later. Orthoclase that occurs between the plagioclase crystals with straight, regular boundaries against them is also probably magmatic, likewise such straight-edged grains as form the inner parts of some of the large penetrating grains. Quartz, which occurs in the interstices of the plagioclase crystals and as occasional inclusions in the potash feldspars, is also regarded as magmatic. Some of the grains of accessory minerals which appear as inclusions and unrelated to crystal boundaries and cleavages may belong to this group, but the evidence is not wholly clear.

Omitting possible accessory minerals, the mineral succession during the magmatic stage is pyroxene, hornblende and plagioclase, biotite, orthoclase, and quartz—the normal sequence for crystallized igneous rocks.

Minerals with the penetrating relationships and which, because of contained remnant inclusions, interpreted as formed by replacement, include most of the orthoclase, all the microcline and albite, some of the biotite and quartz, the larger part, if not all of the accessory minerals, and the actinolite and various other so-called secondary products.

Because so much of the orthoclase embays and contains remnants of plagioclase and hornblende, most of it must have been added after these minerals had formed and hence after the rock had largely, if not entirely consolidated. In some cases the orthoclase has been added to grains interpreted as magmatic with the contact between the two marked by slight differences in extinction. The microcline, because of its greater abundance, shows the replacing relationships even better than the orthoclase. There are few of its grains which are not littered with remnants or that do not show phanton outlines of the plagioclase grains, and virtually no grains which do not embay irregularly and deeply into bordering crystals of orthoclase and plagioclase. The microcline appears to be wholly post-magmatic and entirely the product of

replacement. As the albite is contained perthitically in the microcline and as rims on and as fracture-directed veinlets in the microcline crystals, its position as one of the second group of minerals is securely established. The albite shows a marked preference to enter the microcline and replace it perthitically, but, where particularly abundant, the remaining albite replaces the microcline from boundaries and fractures forming the rim and veinlet structures. Quartz occurring as lobes that penetrate the boundaries of the microcline and albite grains is also late. Thus the sequence established so far is orthoclase, albite, and quartz.

The position of some of the other minerals is not quite so evident, but of those that remain all are at least somewhat younger than the microcline and some are as young as the quartz. Probably the oldest of these minerals is the actinolite with its more or less selective penetration and replacement of the pyroxene, hornblende, and bordering feldspar grains. The grains of biotite which occur between the crystals of perthitic microcline and some of those that penetrate the hornblende crystals are probably little younger than the actinolite.

As most of the so-called accessory minerals show a preference for grain boundaries and cleavages of the feldspars and ferromagnesian minerals and a more or less close association with the late quartz, they were probably introduced at about the same time as the quartz, but not altogether simultaneously Such minerals as garnet, zircon, apatite, and sphene were not found in contact with each other and their succession can not be established. Each penetrates the various feldspars, and the garnet and sphene contain included remnants. Because of the mantling relationships magnetite is known to be older than sphene. The position of the remaining minerals is better known. Epidote has been observed as rims on magnetite, sphene, and allanite, as grains replacing hornblende and biotite, and as replacing veinlets in microcline. Most of the chlorite is associated with epidote as a replacement of the ferromagnesian minerals. The saussuritization of the plagioclase with formation of aggregate zoisite and sericite occurred perhaps at the close of the magmatic stage or probably in part during the later stage of alteration. The sericitic patches not confined to plagioclase cores may represent a rather late development, preceding perhaps the deposition of pyrite, some of whose grains vein and replace magnetite. The mineral succession of both the magmatic and post-magmatic minerals is shown in Table I.

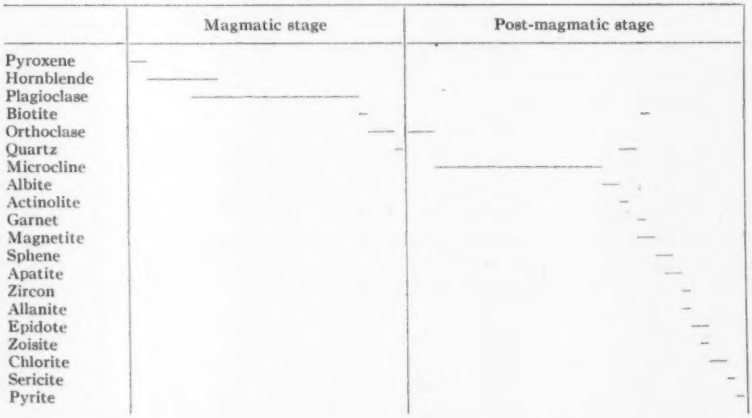
Genesis.—Were the minerals of replacing habit subtracted from the monzonitic rocks and the replaced minerals restored, there would result a rock of dioritic composition not unlike some of the marginal rock (Fig. 2) and the more calcic inclusions in the more central parts (Figs. 3, 4). But because of the extensive replacement by potash feldspar, the original pyroxene-hornblende diorite with accessory orthoclase and quartz has been changed to rock of average monzonitic composition. Where little potash feldspar was introduced, there was little change in composition and for that reason much of the marginal rock approaches diorite, but locally even the marginal rock has been so enriched in potash feldspar that it is in part converted to coarse, porphyritic syenite composed almost entirely of perthitic microcline (Fig. 5). The in-

troduction of potash feldspar was so general that most of the bodies have been made prevailingly monzonitic, in part even syenitic.

The change in the composition of the intrusives after their consolidation was apparently the work of potash-rich solutions from the magma reservoir which acted upon already crystallized material. These potash-rich solutions capable of converting lime-soda feldspar and ferromagnesian minerals to potash feldspars are regarded as hydrothermal. Initially these solutions in reacting with the still hot rock possessed so much heat that orthoclase was the first mineral formed, but, as temperatures declined at the source and in the rock above, microcline was deposited in much greater quantity in part at the expense of the earlier orthoclase. Replacement of the plagioclase by the potash feldspars released sodium which entered the solutions and as the potash was removed the sodium content continued to increase. Eventually the sodic solutions soaked into the microcline and replaced it perthitically by albite and then by grains along margins and fractures. After removal of the sodium the solutions deposited the remaining constituents as quartz and the various accessory and secondary minerals in more or less regular order probably determined by falling temperatures.

TABLE I.

MINERAL SUCCESSION.



Such post-consolidation changes as expressed by the Coeur d'Alene monzonite are by no means uncommon. Conversion of gabbroic rock to quartz monzonite by potash-bearing emanations has been described by Gillson [5] in the Pioche district, Nevada, and more or less similar conversion of quartz diorite and granodiorite to quartz monzonite and granite by potash-rich solutions ris-

[5] Gillson, J. L., Petrography of the Pioche district, Lincoln County, Nevada: U. S. Geol. Survey Prof. Paper 158–D, pp. 77–86, 1929.

ing from the magma reservoir below has been described by Chapman[6] in New Hampshire rocks. Similar phenomena have also been observed by the writer[7] in the rock of the Idaho batholith where addition of potash feldspars and quartz changed an originally dioritic rock to granodiorite and quartz monzonite, but, although the batholithic rock was made more alkalic, it was not so extensively enriched as the younger and genetically unrelated monzonitic rocks of the Coeur d'Alene district. A survey of the more recent literature discloses that introduction of potash into already crystalline rock is a fairly common process.

Exomorphism.—The contact metamorphism associated with the emplacement of the monzonitic rocks was not studied in detail, but certain specimens collected as igneous rock in marginal zones proved to be highly altered sedimentary rocks containing the same minerals as in the intrusive rocks. In these metamorphic derivatives the minerals have the same relationships and sequences as in the endomorphosed igneous rocks (Figs. 19–22); but, in contrast to the igneous rocks, the ferromagnesian minerals and the feldspars are filled with remnant grains of quartz inherited from the sedimentary host. Rock of this nature was also observed by Calkins[8] on Ninemile Creek and he commented particularly on the striking poikilitic character of the pyroxene, hornblende, and microcline with their innumerable microscopic grains of quartz. Rock of this kind appears to represent a local intense phase of metamorphism, for most of the contact aureole shows only a coarsening of grain and development of mica and a few other minerals.[9] There thus appears to have been some local "granitization" associated with the intrusion and the transference of some materials into the invaded rock during both magmatic and post-magmatic stages.

BLEACHED ZONES.

Much attention is being directed at present to zones of extensively bleached rock along which recent ore discoveries have been made.[10] These zones are characterized by an abundance of sericite and represent rock that has been notably enriched in potash. In this respect the zones of bleached rock are like the potash-enriched monzonites and are believed to be another manifestation of the work of potash-rich solutions rising from a deep magmatic source.

Distribution and Structural Relations.—The bleached zones trend in long dimensions with the major structural features and are intimately associated with anticlinal folds and more or less closely paralleling faults.[11] The zones of alteration that are receiving most attention are those comprising the "Silver Belt" and extending from a point just west of Big Creek eastward to

[6] Chapman, C. A., Geology of the Mascoma quadrangle, New Hampshire: Geol. Soc. America Bull., vol. 50, pp. 167–170, 1939.

[7] Anderson, A. L., Endomorphism of the Idaho batholith: Geol. Soc. America Bull., vol. 53, pp. 1099–1126, 1942.

[8] U. S. Geol. Survey Prof. Paper 62, op. cit., pp. 51–52.

[9] Calkins, F. C., U. S. Geol. Survey Prof. Paper 62, op. cit., pp. 49–51.

[10] Sorenson, R. E., Silver Summit opens rich ore: Eng. and Min. Jour., vol. 149, No. 7, pp. 70–73, 151, 1948.

[11] Sorenson, R. E., op. cit., p. 73.

the Idaho-Montana line, a distance of about 18 miles (Fig. 1). This belt lies between the Osburn and Placer Creek faults and the bleached zones persist without important interruptions for the full 18 miles. Locally the zones pinch and swell, in places reaching widths up to several thousand feet, and here and there cross prominent faults at small angles. These zones of bleaching have been found to be much wider at the surface than at deeper levels, apparently because the greater rock permeability nearer the surface permitted wider diffusion of the altering solutions, which were directed upward along faults into crests of fractured, sharply bent anticlines and along bedding planes and cleavages. The bleached zones in the highly mineralized part of the Silver Belt have been studied and mapped in detail.[12]

Physical and Compositional Characteristics.—The term "bleaching" as used in the Coeur d'Alene district refers to the lighter color of the rock as a result of the alteration that has taken place. In these zones of alteration the color of the rock regardless of its original kind, whether the gray and black colors of the Wallace formation or the purplish colors of the St. Regis, is changed to a pale greenish-gray, the result of the rather intense sericitization. In general the argillaceous rocks have been most completely altered, but where alteration has been especially intense even the massive quartzites and the limestones [13] have been changed to a sericite rock. Where the alteration is incomplete, remnants of the unbleached rock may be retained in the bleached. The sericitization has generally been accompanied by the introduction of more or less sparsely disseminated pyrite and in some zones by minor amounts of carbonate minerals, particularly calcite, ankerite, and siderite. These are apparently all products of hydrothermal alteration.

ORE DEPOSITS.

The ore deposits along the Silver Belt show a strikingly close relationship with these zones of sericitized, bleached rocks. Most of the veins are in the bleached rock, but as the veins cross the bleached zones at small angles, some of them enter unbleached rocks.[14] The metallization is thus later and somewhat independent of the alteration, but, although the distribution of the ore does not entirely agree with that of the sericite, the ore deposits and the alteration are in general developed along the same zones of faulting. As pointed out by Sorenson,[15] structural adjustments after the rocks had been sericitized and impregnated by carbonates and disseminated pyrite provided the openings along which carbonate and quartz veins were formed and considerable pyrite and perhaps some chalcopyrite and tetrahedrite deposited. Commercially important amounts of silver, lead, zinc, and copper were then added after the quartz and carbonate veins had been reopened by further structural adjustments.

[12] Shenon, P. J., and McConnel, R. H., The Silver Belt of the Coeur d'Alene district, Idaho: Idaho Bur. Mines and Geology Pamph. 50, 1939.

[13] Anderson, A. L., Geology and metalliferous deposits of Kootenai County, Idaho: Idaho Bur. Mines and Geology Pamph. 53, pp. 54–55, 1940.

[14] Shenon, P. J., and McConnel, R. H., Pamph. 50, op. cit., pp. 8–9.

[15] Eng. and Min. Jour., vol. 149, No. 7, 1948, op. cit., p. 73.

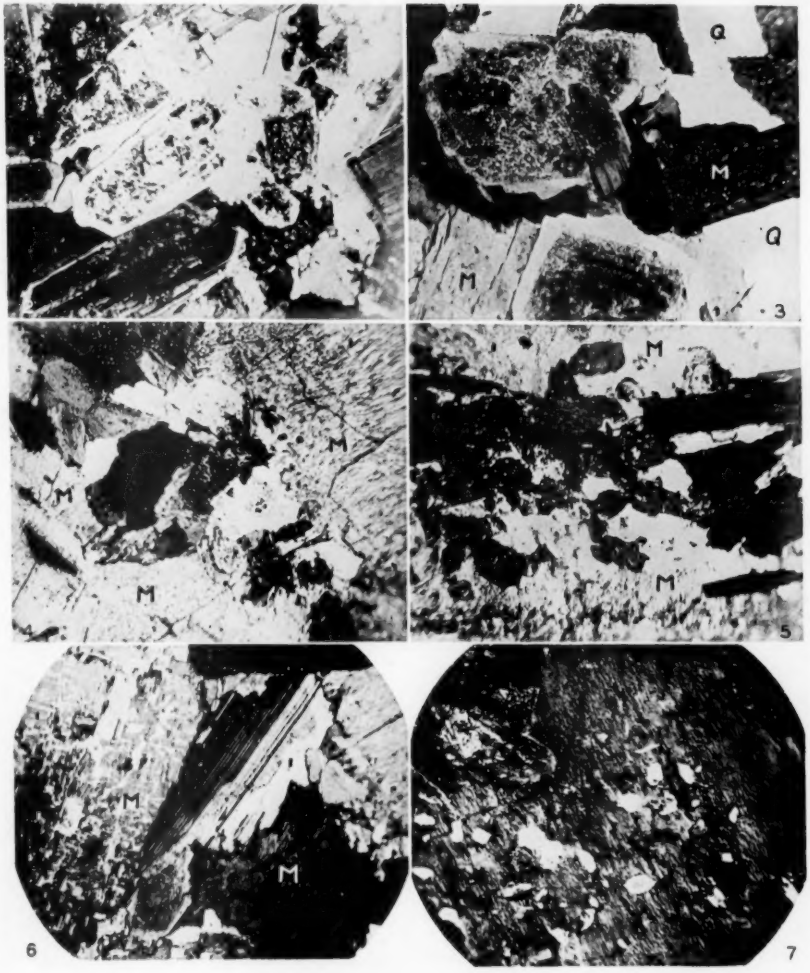
Much of the mineralization in other parts of the Coeur d'Alene district has been accompanied by more or less extensive sericitization and most of the ore deposits, except those at the margin of the monzonites, have an intimate relationship with sericitized, bleached rocks, though the relations are not everywhere exactly the same as along the Silver Belt.

CONCLUSIONS.

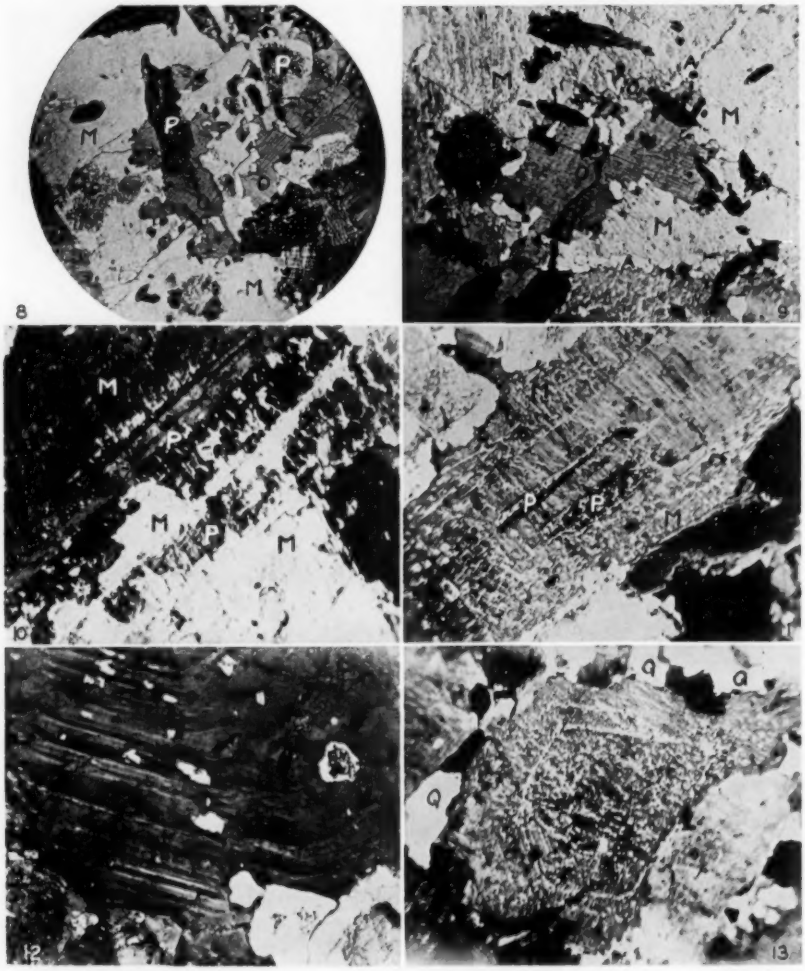
The monzonitic rocks, the zones of bleaching, and the mineralization in the Coeur d'Alene district all show an intimate dependence on a deeply-seated, differentiating magma. In a part of the district portions of the magma were emplaced at high levels and began consolidation as pyroxene-hornblende diorite, but while consolidation was under way, differentiation through extensive crystal fractionation in the magma body below produced hydrothermal solutions rich in potash and to much lesser extent in titanium, phosphorus, and other elements. These solutions moved upward through the hot crystalline rock and at the temperatures then prevailing replaced much of the rock by potash feldspar and variable amounts of other minerals, converting the dioritic rock and some of the bordering sedimentary rock in large part to monzonite and syenite. Some orthoclase was formed during the earliest stage of alteration when temperatures were highest, but for the most part the temperatures favored the deposition of microcline. As the potash feldspar replaced the plagioclase and other minerals containing sodium, the solutions became increasingly sodic through interchange of elements and finally the sodic solutions attacked the microcline and replaced it in considerable part by perthitic albite and locally, where the sodium was exceptionally abundant, also by rims and discrete grains of albite. By then the depositional temperatures of the remaining minerals had been reached and a little actinolite and biotite were formed. Then magnetite, sphene, zircon, apatite, and quartz were deposited, garnet locally, and finally allanite, epidote, zoisite, sericite, and pyrite.

In other parts of the district deeply extending faults reached to magmatic depths but failed to divert the magma to higher levels. These faults, however, did serve as channelways for the potash-rich solutions that escaped from the magma reservoir. As these solutions did not have to move upward through hot igneous rock, they did not maintain their source temperature for any great distance. Loss of heat to the relatively cool sedimentary wall rocks soon reduced the temperature to the formational range of sericite, and, as the potash-rich solutions moved upward along the zones of faulting, they caused extensive sericitization (bleaching) of the rock. Structural adjustments along the zones of bleached rock then provided openings for the movement of the ore-bearing solutions.

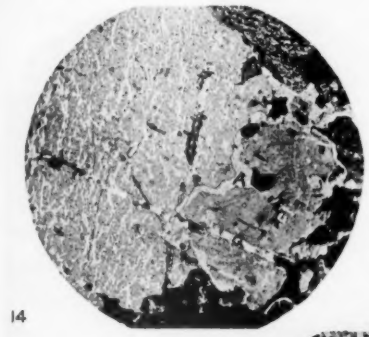
Metallization throughout the district has been more or less closely associated with potash-rich solutions. It apparently followed closely after the solutions that produced the extensive sericitization along the structural zones of the Silver Belt; it also closely attended the solutions that produced the intense endomorphism of the monzonitic rocks. In the latter case potash was fixed in the monzonitic rocks and the high temperatures did not permit much

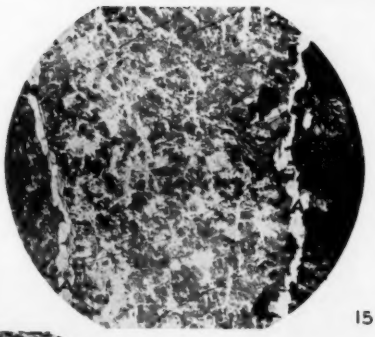


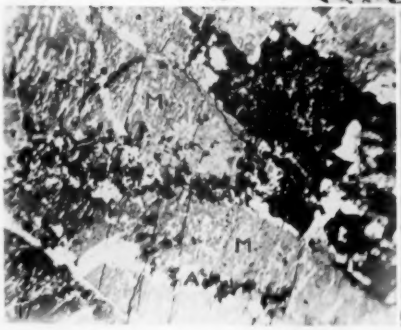
FIGS. 2-7. Titles at end of paper.

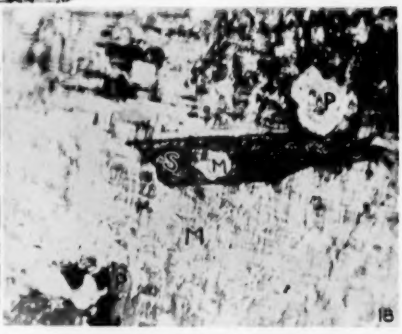


FIGS. 8-13. Titles at end of paper.

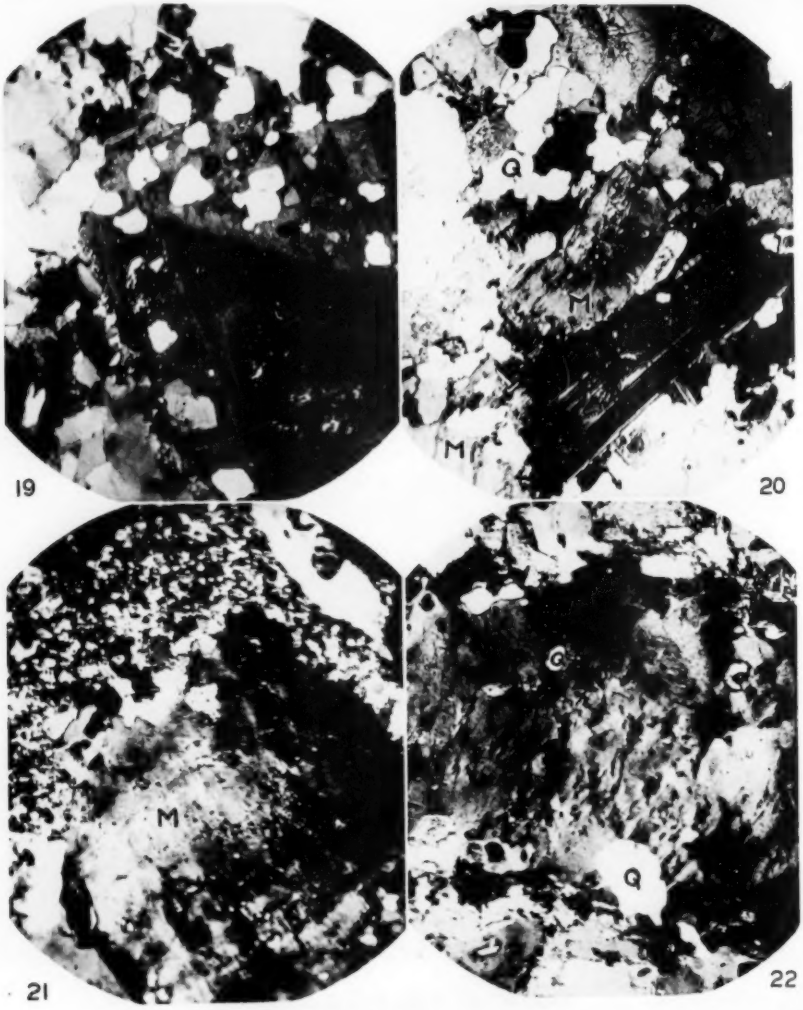








FIGS. 14-18. Titles at end of paper.



FIGS. 19-22. Titles at end of paper.

sericite to form, except at some distance away. Some ore, however, was deposited locally at the margin of the largest monzonitic body in deposits of the contact-metamorphic type (Success mine).[16] Outward from the monzonitic border the associated high-temperature silicates decrease in abundance and the ore eventually passes into rock that is sericitic. Through the Burke-Mullan region the ore deposits in general show a marked vertical and horizontal zonal distribution about the monzonite.

The close association of the ore deposits with rocks that had just been greatly enriched in potash suggests that the formation of potash-rich solutions was a necessary prelude to metallization. Whether or not the association implies that the ore solutions, like the potash-bearing solutions, were alkaline is open to question. Some may feel that the alteration and the metallization are so closely related that the alkalinity of the one carries over into the other. On the other hand others may point to the structural break between the alteration and ore deposition, and, while accepting the alkalinity of the earlier solutions, may reject the assumption that the ore-bearing solutions also were alkalic. Instead they may infer that the altering solutions and the ore solutions being of slightly different ages may have evolved as more or less closely affiliated but separate phases with the ore contained in acidic solutions. No evidence has yet been found locally to indicate one way or another. In the Coeur d'Alene district the sericitized (bleached) zones certainly offer the most likely places for ore discovery.

CORNELL UNIVERSITY,
ITHACA, NEW YORK,
Nov. 28, 1948.

EXPLANATION OF PLATES.

FIG. 2. Typical textural relationships of zoned plagioclase crystals of marginal dioritic rock of the smaller monzonitic bodies near Dago Peak. Centers of plagioclases are more or less completely saussuritized and are encircled by rims of clear, unaltered sodic plagioclase. Textural relationships indicate magmatic crystallization. X-nicols. × 20.

FIG. 3. Zoned, saussuritized plagioclase crystals with clear sodic rims within main monzonitic body near Gem. Absence of potash feldspar gives the appearance of a small island of dioritic rock with only minor microcline (M) and quartz (Q) in interstices. Actually the crystals are a part of a very small area that escaped extensive penetration by late potash feldspar. X-nicols. × 20.

FIG. 4. Remnant of original consolidated (dioritic) rock within main Gem stock enclosed between and penetrated and partly replaced by large crystals of microcline (M) which locally make up bulk of rock. Such remnants are common throughout the body and serve as evidence that the rock originally was less alkalic than the present and that the change has come about as the result of the widespread introduction of potash feldspar into the already crystalline rock. X-nicols. × 20.

FIG. 5. Narrow strand of hornblendic rock within coarse porphyritic syenite of marginal zone near Gem. These dark hornblende crystals and small remnants of plagioclase are all that remain of the original dark hornblendic diorite that was permeated and almost completely replaced by microcline (M). X-nicols. × 20.

[16] Umpleby, J. B., and Jones, E. L., Jr., Geology and ore deposits of Shoshone County, Idaho: U. S. Geol. Survey Bull. 732, pp. 32–41, 1923.

FIG. 6. Characteristics of much of the plagioclase in the monzonitic bodies—deep and uneven penetration (replacement) by potash feldspar, particularly microcline (M). By such substitution of potash feldspar for plagioclase the rock has changed from diorite to monzonite and syenite. X-nicols. × 28.

FIG. 7. The potash feldspar introduced into the rock is commonly crowded with remnant grains and shadowy inclusions of earlier minerals, particularly plagioclase feldspar and to lesser extent hornblende and quartz. Such grains of potash feldspar have obviously developed largely at the expense of earlier minerals. The potash feldspar is microcline. X-nicols. × 28.

FIG. 8. Most of the orthoclase (O) has formed in the rock by penetration and replacement of the plagioclase grains (P). Then it has in turn been penetrated and extensively replaced by microcline (M), which in places has extended entirely through, dividing it into irregular, oriented, remnant islands, and engulfing and embaying the grains of plagioclase. X-nicols. × 20.

FIG. 9. Hornblende crystals (dark) are not always so easily replaced as the plagioclase grains and may remain as engulfed inclusions within the potash feldspars. In this section the orthoclase (O) has been irregularly replaced by perthitic microcline (M), in part with remnants as oriented islands, and then partly rimmed by albite (A), which, however, has favored the microcline margins over those of orthoclase. X-nicols. × 20.

FIG. 10. Shows a stage in the replacement of plagioclase (P) by microcline (M). The light grain of microcline has penetrated unevenly into the plagioclase and in such a way as to isolate a part of it as a long irregular peninsula, perfectly oriented with the mainland. X-nicols. × 50.

FIG. 11. Microcline (M) that has selectively replaced all but two oriented-island remnants of plagioclase (P) near the center of the former plagioclase crystal. The microcline preserves faintly the former outline and also the zonal banding of the plagioclase crystal. Other grains of plagioclase in this particular section are only partly penetrated and replaced at margins. X-nicols. × 20.

FIG. 12. Zonary banding in microcline interpreted as the result of oscillation in the proportion of soda and potash in successive shells. Note inclusions of remnant plagioclase grains within the microcline. X-nicols. × 50.

FIG. 13. Zonary structure in microcline interpreted as the product of preferential development of perthitic albite in directions parallel to crystallographic boundaries of the microcline. Note quartz grains (Q) partly lobate against the microcline at grain margins. X-nicols. × 20.

FIG. 14. Perthitic character of much of the microcline and the albite rims (A) developed about microcline grains, usually in rock in which the perthitic character is most developed. Some stranded remnants of hornblende remain in the microcline, and locally a veinlet containing quartz (Q) cuts the microcline. X-nicols. × 20.

FIG. 15. Patchy, perthitic development of some of the microcline, which may be the result of replacement, and the prominent albite rims composed of aggregates of small albite crystals at the margins of or between the microcline grains. X-nicols. × 20.

FIG. 16. Aggregates of relatively coarse albite crystals (A) which have penetrated inward and have extensively replaced the microcline grains (M), in part retaining irregular remnants of the microcline as inclusions. X-nicols. × 20.

FIG. 17. Fractured perthitic microcline (M) that has been penetrated by irregular veinlets of replacing albite (A) along fractures. The albite in the veinlets is younger than and apparently independent of that in the perthitic intergrowths; yet albite rims and veinlets occur only where the microcline is highly perthitic. X-nicols. × 20.

FIG. 18. Microcline penetrated by sphene (S) in which there is an oriented remnant of the microcline host (M). The sphene is interpreted as a late introduction into the rock and formed largely as a replacement of the feldspars and horn-

blende. Note inclusions of plagioclase (P) within the microcline. X-nicols. × 50.

FIG. 19. Section of exomorphosed quartzite showing a zoned plagioclase crystal with numerous inclusions of quartz. The plagioclase is developed in and replaces the quartzite. X-nicols. × 35.

FIG. 20. With increase in number of plagioclase crystals and with an infiltration of microcline (M) the exomorphosed rock takes on the textural characteristics of an igneous rock with retained grains of quartz (Q) and patches of the original quartzite. X-nicols. × 35.

FIG. 21. Microcline (M) also forms in the quartzitic rock of the exomorphosed zone, generally as irregularly bordered crystals with numerous included remnants and shadows of the host rock and of the new-formed plagioclase crystals. X-nicols. × 35.

FIG. 22. With more complete feldspathization, the exomorphosed rock becomes virtually indistinguishable from the endomorphosed rock of the intrusive bodies. Occasional remnant grains of quartz within the feldspars of the monzonitic bodies suggest that "granitization" of the sedimentary rock may have had a fairly prominent part in their development. X-nicols. × 35.

TRANSPORT AND DEPOSITION OF THE NON-SULPHIDE VEIN MINERALS. IV. TOURMALINE.

F. GORDON SMITH.

ABSTRACT.

Tourmaline was synthesized by heating the component oxides with water to 400–450° C in a high pressure autoclave. The degree of filling was 60–70 percent at room temperature. The limits of stability of tourmaline at 400–450° C as functions of the concentration of Na_2O and B_2O_3 were determined. It is concluded that tourmaline is stable in water solutions which have a low alkalinity and low to high solute concentration, but it is unstable in strongly acid and strongly alkaline solutions. Albite was found to be stable along with tourmaline in alkaline solutions containing less than approximately 45 percent of water.

SYNTHESIS.

In geological literature, tourmaline is often stated categorically to be a "pneumatolytic mineral." That is, the statement is made that tourmaline is formed through the agency of gases evolved from magmas. Further, it is often inferred that the responsible gases are strongly acid in the chemical sense. Many investigators have doubted both the gaseous and strongly acid character of the normal magmatic emanations, but the question can only be settled after the limits of stability of tourmaline and associated minerals have been determined.

Tourmaline is a very complex mineral, which has been given many generalized formulae, but one suggested by Penfield (6)[1] has often been quoted:

$$R^1_9Al_3(B\cdot OH)_2Si_4O_{19}.$$

Many elements have been reported to be present in tourmaline in significant amounts, such as Na, Li, Ca, Mg, Fe, Mn, Cr, and F. Apparently the structure contains essential but mutually replaceable monovalent elements such as H, Na, Li, divalent elements such as Ca, Mg, Fe, Mn, and trivalent elements such as Al, Fe, Cr, as well as the essential but not replaceable elements B and Si. All of these are coordinated by oxygen and a small amount of fluorine. Obviously the conditions under which such a complex structure could be provided with all of the essential components must be restricted in comparison with the conditions of deposition of a simple mineral such as quartz.

Tourmaline occurs as a late stage magmatic mineral, a pegmatite mineral, and a high temperature vein mineral. It is commonly associated with silicates such as feldspar, mica, quartz, topaz, and with cassiterite, scheelite, wolframite, and other high temperature oxide minerals. It occurs in a number of high temperature gold-quartz veins, where it appears to be associated in time of deposition with pyrite and chalcopyrite. The literature contains a number of

[1] Numbers in parentheses refer to Bibliography at end of paper.

compilations of occurrences of tourmaline but it would add little to this work to review them.

Early attempts at the synthesis of tourmaline were unsuccessful. It was reported by Fouqué and Lévy (1) that up to 1882 undoubted tourmaline had not been made, but in spite of this, they believed that tourmaline is formed in nature with the aid of volatile halides. The first successful synthesis was by Frondel *et al.* (2), by the method of heating a glass (made by melting tourmaline) with an aqueous solution of magnesium and alkali borates at a temperature of 400° to 500°. The preliminary notice by Frondel of the successful crystallization of tourmaline appeared in print a few days after the identification of tourmaline in the products of one of the experiments in this laboratory, and since then we have been in communication so that there will not be a duplication of effort.

A series of experiments were started in the spring of 1947 to determine if tourmaline can be crystallized in the laboratory, and if so, to determine some of the limiting conditions of its stability. It was realized that it would take many years to study the full system ($SiO_2 - Al_2O_3 - B_2O_3 - Na_2O - LiF - MgO - FeO - Fe_2O_3$, etc.) so that the method of reconnaissance experiments was used. The initial experiments involved simultaneous variations until tourmaline appeared. Then the variations were made systematically in several directions in order to outline the field of stability of the mineral. Tourmaline appeared in the fourteenth exploratory run.

No apology is offered for the apparently arbitrary nature of the experiments. These are only of a preliminary qualitative nature. If geologists were to wait for physical chemists to move out from simple systems to complex ones containing minerals such as tourmaline, it would be decades before useful data would appear for use. Some of the principal questions must be answered with dispatch in order to direct experimental effort into practical channels.

The experimental technique was to heat the essential components of tourmaline in contact with water and identify the crystalline products after rapid cooling. The pressure vessel used to contain the system was similar to the one described in the second paper of this series (4). The internal volume was 143 cc. The degree of filling of the bomb by the charge was 60–70 percent, and the variation in the water content between different experiments determined the variation in the degree of filling, so that the pressure during heating did not vary as much as it would have without this compensation. The actual pressures developed during heating were not measured, but were probably over 1,000 atmospheres at the maximum temperature of each experiment. The time taken to reach the desired temperature was about 6 hours, and the time taken to cool to room temperature, about 1 hour. After the conditions were found where tourmaline crystals grew readily, the limiting concentrations of various components were determined near 400° C. The amounts of the components in each of the experiments and identified crystalline products are given in Table 1. The synthetic tourmaline crystals were identified by optical methods, confirmed by comparison of X-ray powder diffraction pictures of the synthetic and natural material. Photographs of the synthetic crystals are shown in Figure 1. X-ray diffraction pictures are shown in Figure 2.

TABLE 1.

Exp. No.	Components in bomb charge, gm.										Other conditions					Crystalline products identified
	H_2O	NaOH	Borax	H_3BO_3	SiO_2[1]	Al_2O_3[2]	MgO[3]	LiF	Others	Total	Na_2O %	B_2O_3 %	$\frac{Na_2O}{B_2O_3}$	Temp. ±10° C	Time, days	
T1	67.0	10.0	—	5.0	4.0	1.0	0.1	2.0	—	89.0	8.71	3.16	2.75	450	1.0	chlorite, mica.
T2	67.0	10.0	—	5.0	4.0	1.0	0.1	2.0	—	89.0	8.71	3.16	2.75	450	2.5	mica, analcite.
T4	61.5	10.0	—	10.0	8.0	0.5	0.05	2.0	—	92.0	8.42	6.12	1.38	455	2.5	albite.
T5	56.5	10.0	—	15.0	13.0	0.5	0.05	3.0	—	98.0	7.91	8.62	0.917	451	2.5	(all glass).
T7	55.5	3.0	—	5.0	4.0	0.5	0.05	—	NaF =1, LiCl =1	70.0	3.32	4.02	0.827	402	3.5	albite.
T8	55.5	—	10.0	—	4.0	0.5	0.05	0.5	—	70.5	2.31	5.19	0.445	402	3.5	albite (with glass).
T9	58.7	—	5.0	—	4.0	0.3	0.03	0.5	—	68.5	1.19	2.67	0.445	400	3.5	quartz, clay.
T10	58.2	—	10.0	5.0	2.5	0.3	0.03	1.0	—	77.0	2.11	8.41	0.251	425	2.5	quartz.
T11	60.5	—	8.0	—	4.0	0.5	0.05	0.5	—	73.5	1.76	3.98	0.445	460	1.5	albite, riebeckite (tourmaline seed crystal corroded).
T12	55.5	—	8.0	10.0	4.0	0.5	0.05	1.0	—	79.0	1.64	9.45	0.174	460	1.5	quartz, clay (tourmaline seed crystal corroded).
T13	55.5	—	8.0	20.0	3.0	0.5	0.05	2.0	—	89.0	1.46	14.70	0.099	413	1.0	quartz, clay (tourmaline seed crystal corroded).
T14	54.0	—	12.0	20.0	2.5	0.5	0.05	3.0	Ferrous Amm. Sulfate =1	93.0	2.10	16.83	0.125	401	3.0	quartz, riebeckite, hematite, *tourmaline* (tourmaline seed crystal not changed).
T15	49.5	—	20.0	15.0	3.0	0.5	0.05	3.0	Ferrous Amm. Sulfate =1	92.0	3.54	17.14	0.207	422	3.5	quartz, clay, riebeckite.
T16	41.0	—	25.0	40.0	2.5	0.5	0.05	3.0	Ferrous Amm. Sulfate =1	113.0	3.60	28.03	0.128	405	1.5	quartz, riebeckite.
T17	54.0	—	9.0	25.0	2.5	0.5	0.05	3.0	Ferrous Amm. Sulfate =1	95.0	1.54	18.30	0.080	405	1.5	quartz, clay, *tourmaline*.
T22	34.0	—	24.0	47.5	2.5	0.5	0.05	3.0	Ferrous Amm. Sulfate =1	112.5	3.47	31.59	0.110	420	2.5	clay, *tourmaline*.
T23	35.0	—	25.0	50.0	2.5	0.5	0.05	0.3	Ferrous Amm. Sulfate =1	114.3	3.56	32.61	0.109	412	2.5	quartz, clay, pyrite.
T24	41.5	—	35.0	50.0	3.0	0.5	0.05	1.0	Ferrous Amm. Sulfate =1	132.0	4.31	31.04	0.139	405	2.5	clay, *tourmaline*.
T25	40.5	—	40.0	50.0	3.0	0.5	0.05	1.0	Ferrous Amm. Sulfate =1	136.0	4.79	31.48	0.152	450	1.0[5]	quartz, clay, hematite, pyrite, *tourmaline* (tourmaline seed crystal grew on one end).
T26	28.5	—	45.0	50.0	3.0	0.5	0.05	1.0	Ferrous Amm. Sulfate =1	129.0	5.68	34.60	0.164	415	1.5	clay, *tourmaline*.
T27	5.5	—	63.9	66.1	5.0	0.5	0.05	1.0	Ferrous Amm. Sulfate =1	143.0	7.28	42.90	0.169	415	3.5	quartz, clay, pyrite, *tourmaline* (tourmaline seed crystal grew on one end).
T29	(−23.0)[4]	—	80.2	63.8	6.0	0.4	0.05	1.7	Ferrous Amm. Sulfate =1, NaF =1.7	130.5	10.00	50.00	0.200	415	2.5	albite, riebeckite.
T30	(−19.5)	—	80.2	63.8	9.5	0.4	0.05	1.7	Ferrous Amm. Sulfate =0.5	136.5	9.56	47.8	0.200	434	1.5	albite, clay, riebeckite.
T31	(−40.0)	—	86.1	80.9	9.5	0.4	0.05	2.0	Limonite =1	140.0	10.00	55.0	0.182	440	3.5	albite, clay, hematite.
T32	(−44.0)	—	86.1	80.9	9.5	0.4	0.05	2.0	Ferrous Amm. Sulfate =10	145.0	9.65	53.1	0.182	415	2.5	albite, clay, pyrite, *tourmaline*.
T33	(−31.0)	—	71.4	82.4	9.5	0.4	0.05	2.0	Ferrous Amm. Sulfate =10	145.0	8.0	50.0	0.160	449	2.5	quartz, clay, pyrite.
T34	(−34.0)	—	80.3	76.6	9.5	0.4	0.05	2.0	Ferrous Amm. Sulfate =10	145.0	9.0	50.0	0.180	425	2.5	quartz, hematite, *tourmaline*.
T35	54.0	—	12.3	27.5	2.5	0.5	0.25	1.0	Ferrous Amm. Sulfate =2	100.0	2.00	20.0	0.100	411	2.5	quartz, *tourmaline*.
T36	56.1	—	6.15	31.5	2.5	0.5	0.25	1.0	Ferrous Amm. Sulfate =2	100.0	1.00	20.0	0.050	409	2.5	quartz, pyrite, *tourmaline*.
T37	47.2	—	6.15	40.4	2.5	0.5	0.25	1.0	Ferrous Amm. Sulfate =2	100.0	1.00	25.0	0.040	420	2.5	clay, hematite, pyrite.
T38	55.4	—	12.3	27.5	2.5	0.5	0.25	1.0	Fe_2O_3 =0.5	100.0	2.00	20.0	0.100	405	2.5	*tourmaline*.

[1] The silica was added in the form of a dried gel, which contained 22 percent of water by weight.

[2] The alumina in Experiments T1 to T27 was added in the form of a soft gel, and in Experiments T28 to T37, in the form of ignited powder.

[3] The magnesia in Experiments T1 to T27 was added in the form of a soft gel, and in Experiments T28 to T37, as $MgCO_3$ powder.

[4] This notation means that some of the water which had been added as water of crystallization was boiled out of the charge before adding to the bomb.

[5] This charge was cooled slowly (18 hours) to see if the tourmaline formed at the high temperature would decompose at a lower temperature. This apparently did not take place.

FIG. 1. Photomicrographs of synthetic tourmaline crystals (Experiment T-35). The crystals are approximately 0.05 mm long. Plane polarized light.

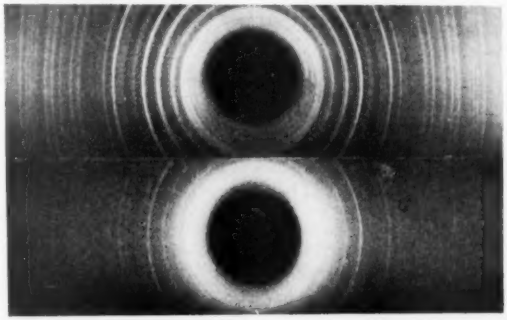


FIG. 2. X-ray powder diffraction patterns of tourmaline: A—Synthetic crystals (Experiment T-14); B—greenish black crystals from Enterprise, Quebec. The radiation was from Cu with a Ni filter, using a camera with a radius of $360/4\pi$ mm.

Figure 3 summarizes some of the limits of stability of tourmaline at 400–450° C, when the concentrations of the abundant alkaline oxide (Na_2O) and the abundant acidic oxide (B_2O_3) are varied simultaneously. In the figure is also shown the measured alkalinity of $Na_2O - B_2O_3$ mixtures, defined as the *p*H of the mixture when diluted with water so that there is 1 gram of anhydrous solute in 1 liter of solution at 25° C (5). It will be seen that in all but the very dilute solutions, tourmaline is stable only in weakly alkaline solutions and unstable in neutral, acid, and strongly alkaline solutions. In dilute aqueous solutions Frondel has found that tourmaline is stable in neutral and weakly acid solutions.[2]

[2] Personal communication from Professor Frondel.

The approximate field of stability of albite is also shown in Figure 3. Albite and tourmaline are incompatible at high water concentrations, but the limits approach and the fields overlap at low water concentrations, as shown. The aluminium mineral stable with tourmaline in dilute solutions is an unidentified clay mineral of micaceous habit but with a small power of crystallizing. Quite possibly a mica such as muscovite would be stable over much of this region if potassium were present in large amounts.

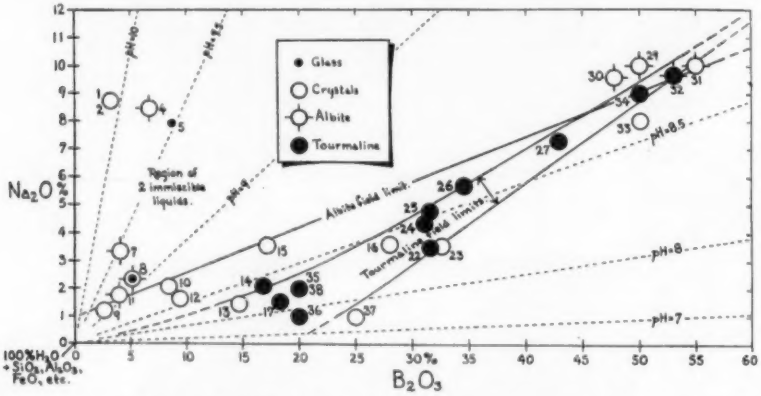


FIG. 3. Relation between the Na_2O and B_2O_3 concentrations and the stability of tourmaline and albite at 400–450° C and 60–70 percent filling of the system at room temperature. The meaning of the *p*H values is explained in the text. The limits of the fields of stability are shown in solid lines. Numbers within the diagram refer to the experiment numbers (T series) in Table 1. The symbols refer to solid phases identified in the products in addition to the water solution.

The iron compound stable on the alkaline side of the limit of stability of tourmaline is a dark grayish blue asbestiform compound which resembles riebeckite. The optical properties of the compound are as follows:

$$n_g = 1.683 \pm 0.001,$$
$$n_m = 1.681 \pm 0.001,$$
$$n_p = 1.679 \pm 0.001,$$
$$n_g - n_p = 0.004 \pm 0.002;$$

elongation negative, X$\wedge$ elongation $= 3° \pm 1°$; pleochroism intense, absorption being X > Y > Z, and

X = dark indigo blue,
Y = medium grey,
Z = pale yellowish green.

The above optical properties are similar to those recorded for various sodic amphiboles, and are nearly the same as those given by various authors for riebeckite ($H_2Na_2Fe_2Si_8O_{24}$).

One of the conclusions from the above data is that tourmaline is unstable in strongly acid solutions. In a previous paper of this series (4), it was pointed out that tin can be transported in hydrothermal solutions in two ways —as a stannate ion in alkaline solutions, or as a simple ion in acid solutions. If cassiterite and tourmaline are found in nature to have been deposited from the same solutions at the same time, then the solutions must have been alkaline, not acid. Since tourmaline accompanies cassiterite in many tin deposits, this reduces very greatly the number of occurrences of tin which could have been formed by acidic pneumatolysis. A similar argument can be used in the case of cassiterite deposits containing albite.

The overlapping of the fields of stability of tourmaline and albite in the isothermal, isopiestic, water-alkali-acid plot may be of some importance. Tourmaline is found in nature with feldspars (including albite), in batholiths and pegmatite dikes. If tourmaline and albite are stable together in contact with a solution which contains less than about 45 percent of water, as the experiments suggest, then they must be crystallized together in nature from the silicate magma near its end stages, and not from the derived hydrothermal solution. Even if the intervening pegmatitic stage has two immiscible liquids, as derived experimentally recently (5), albite and tourmaline would not be stable together in contact with the silicate liquid fraction at the pegmatitic stage. This follows from phase equilibrium relations of the following type: crystals A and B are in equilibrium with solution C; solution C is in equilibrium with solution D; therefore crystals A and B are also in equilibrium with solution D. Solution D in the above discussion is the hydrothermal solution in which water is the dominant component. Therefore albite and tourmaline could not be deposited at the same time from either the hydrothermal solution or the last part of the silicate solution if it is also in equilibrium with the hydrothermal solution. There is no restriction on the solutions depositing either mineral alone. For example, the hydrothermal solution might deposit tourmaline and a mica under one set of conditions, or albite without tourmaline under another.

The relatively narrow range of stability of tourmaline, with reference to the composition of the solutions with which it is in equilibrium, should prove to be useful in further synthesis studies. A large number of pegmatite minerals, since they are apparently deposited from the same solutions that deposit tourmaline, must have fields of stability which overlap that of tourmaline in part at least.

An interesting mineralogical phenomenon was observed in the above work. In a few of the runs, a small fragment of pale pink tourmaline from Brazil was added to the components before heating. Growth of greenish black tourmaline was observed to complete one end only of the crystal (by development of rhombohedral faces) in those experiments where many small tourmaline crystals also formed from the simple components. In the experiments where tourmaline did not form, the seed crystal was found to be etched and decomposed, but again just at one end. The growth of tourmaline in a polar manner has also been noticed in the natural crystals. Krynine (3) has described many examples of authigenic tourmaline overgrowths which develop only on one end of the nucleus grain.

CONCLUSIONS.

1. Tourmaline has been crystallized from its component oxides in a water solution at 400–450° C.

2. Tourmaline has a narrow range of stability with regard to alkalinity, but both of the limits are on the alkaline side except that, when the water concentration is very high, one limit lies on the acid side.

3. Tourmaline is unstable in strongly acid and strongly alkaline water solutions.

4. In alkaline solutions, tourmaline is stable with albite, quartz, hematite, and pyrite.

ACKNOWLEDGMENTS.

I wish to thank Dr. E. W. Nuffield for making the X-ray diffraction patterns, and Mr. P. A. Peach for taking the photomicrographs. The Advisory Committee on Scientific Research of this University facilitated the work by a grant of money for equipment.

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LOGARITHMIC PATTERN IN RIVER PLACER DEPOSITS.

JACQUES B. WERTZ.

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ABSTRACT.

This paper presents the results of a series of 10 experiments made in the laboratory with a wooden trough, supplemented by 10 cases taken from actual placer maps. These data give the following concordant results, checking with each other:

1. Deposition areas and erosion areas alternate with each other.
2. The ore-concentration zones coincide with the erosion areas, whereas the barren zones coincide with the sedimentational areas.
3. The ore-concentration zones occur in a logarithmic sequence as established by log-log diagrams.

In consequence, a law may be postulated as follows: *There is a logarithmic sequence of rich erosion areas alternating with barren sedimentational areas.*

This will prove useful in the interpretation of placer maps, in the checking of the quality of a prospecting, and in the explanation of irregularities, where interference factors are to be taken into consideration.

INTRODUCTION.

INTEREST in this field, hitherto little explored, arose from an experience of more than 10 years in Africa in placer work.

It was decided to begin with a laboratory study of mineral concentration in an experimental alluvial trough, using a mixture of quartz sand and heavy minerals. A highly quantitative approach, admittedly desirable, could not be carried out for lack of time, but at least a beginning could be made.

As this approach was essentially new, basic literature is wholly lacking. What is reported in the first part of this thesis is original experimentation only. In a preliminary fashion, the qualitative laws developed by these ex-

periments proved to be applicable to the field facts observed in African placer deposits.

The results thus certainly indicate that a significant beginning has been made and that further study is merited.

The author wishes to express his indebteness and appreciation particularly to Professor Ch. H. Behre, Jr., of the Geology Department at Columbia University, for his critical reading and much valuable advice during this study and for the correcting of the entire manuscript; to Mrs. M. S. Knox for the constructive criticism of this paper and also to Mr. G. Pardo and Mr. J. N. Perfetti for exchange of ideas and their interest in the subject of this problem.

LABORATORY DATA.

The Apparatus—A wooden sluice-box 11 feet in length was obtained. It was not certain whether the trough should be fed by simultaneous but separate introduction of the placer constituents, or by mixing before feeding and putting both constituents into the trough at once. The latter proved too complex and time consuming to be practical, and only the former was favored; sand and water thus were poured from different conduits.

Plastic tubes 4 feet in length and 1½ inches in diameter were used for this purpose and fitted at the lower end with rubber tubing by clamps. The sand and the water had to be spread laterally as much as could be done for a regular distribution and the tubing was therefore stretched out laterally and equipped with a slit made of 2 brass pieces kept apart by two small wedges.

Water feeding was accomplished by a small rubber hose attached to the upper end of one of the tubes and discharging into it. As water could only be regulated at the faucet and without sufficient pressure due to the high resistance to the flow into the hose, the discharge factor could practically not be varied.

For the sand feeding, a constant pouring of the sand by hand through a funnel at the upper end of the other large tube proved to be the simplest procedure.

The original plan was to graduate the tubes for more quantitative work, but as this procedure was not carried out, their length as used was actually unnecessary and a large funnel could have been used efficiently.

A cardboard stopper closed the lower end of the sand-tube when not in operation. A sand-catcher was designed for the tail of the trough in order to recover the sand. This device simply consisted of a frame supporting a strong piece of cloth.

The only factor that could be changed quantitatively with accuracy and in an important amount was the slope factor, the discharge factor being constant and the load factor slightly variable.

Procedure—The slope was adjusted to 1/50 for the 6 first experiments but was changed to 1/30 for the others, in the hope that the distribution of the scours might be better shown. Unfortunately, regular erosion that forced the stream bed to follow the profile of equilibrium excluded in several cases the possibility of developing good scours. A decrease of the slope, however, would have been preferable.

The sand used was sieved and the grades No. 60 U. S. Standard (*i.e.*, retained on 60 mesh = .250 mm nominal opening), and No. 140 (*i.e.*, retained on 140 mesh = .105 mm) were used. The sand was impure, containing small particles of biotite and ferromagnesian minerals.

Magnetite was added to it at the ratio of 1% for each size. The composition of the sand used was thus respectively:

14 kg 673 sand + 0 kg 146 magnetite No. 60,
1 kg 535 sand + 0 kg 015 magnetite No. 140.

In order to reduce the turbulence at the head of the trough a small dam was placed just below its area of turbulence. The feeding device however was changed later on as shown in B (Fig. 1) in order to prevent the water from coming directly into the sand, thus the mixture of sand and water was smoothly deflected before running into the trough.

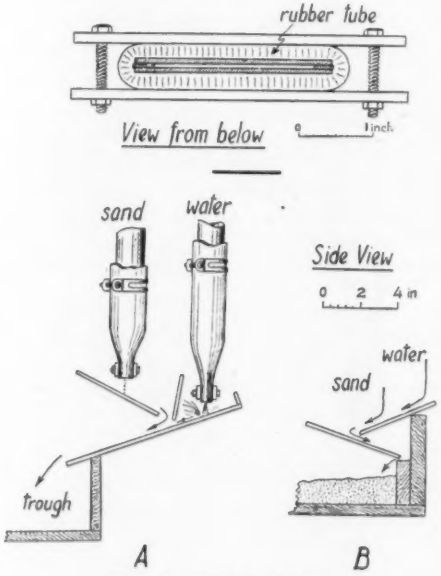

FIG. 1. Feeding device.

The whole experiment thereafter can be divided into two periods: (1) the feeding period, when the sand was fed (approximately ½ to 1 hour) in order to form a stream-bed. This was followed by (2) the erosion period (generally ½ hour or less).

In some cases, especially if erosion had already begun, during the feeding period, it was necessary to level off by hand the upper reaches of the stream-bed to obtain clearer observations.

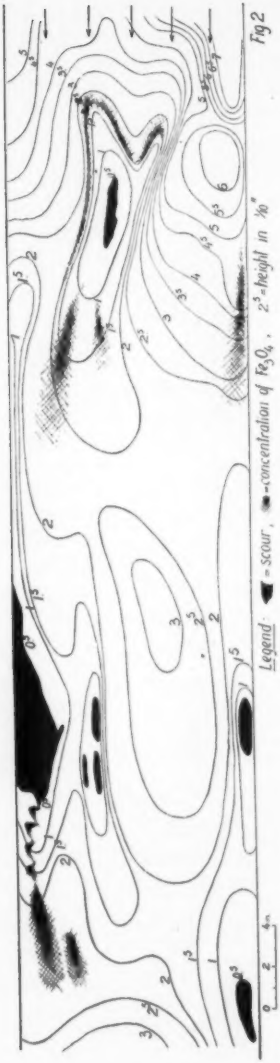

FIG. 2. Preliminary experiment.

EXPERIMENTAL RESULTS.

Surficial Relations between Concentrates of Heavy Minerals and Areas of Erosion.

Although the first experiment was designed solely to test the process of feeding, it revealed interesting details that are recorded on a contour map (Fig. 2), in spite of the fact that only two-thirds of the trough was covered with sand. The following observations were made:

1. Areas of scouring and areas of braiding alternate longitudinally in plan with each other. The scouring areas appear to be cyclic and it was inferred at first that there is an *apparent cycle of erosion and deposition,* though this inference was subject to check by further experiments.

2. The heavy mineral deposition occurs just below the scour, in the erosion area; farther down is the area of sand deposition. In the latter the volume and the force of the water is reduced, mostly by seeping out through the otherwise unsaturated sand. On the other hand, the erosion areas show the sand perfectly removed and these areas correspond to points of greatest velocity of the current. This would be useful in recognizing these areas in the field.

3. All the scours continually shift downstream. They are continually moving, nearly always downward, but in a few cases upwards. Only a movie camera could record the constantly changing pattern.

The series of scours might almost be regarded as "living," actively eroding the stream-bed; then the scours are rapidly destroyed and buried, being replaced by others, downstream or sometimes laterally, then reviving again, to be destroyed again after a short while. This whole activity is governed by a slow downward movement. An upstream movement however may occur at times.

The movements in these two opposite directions are neatly shown by two different and characteristic patterns of erosional ripples, marked in the stream-bed as well as on the water surface (Fig. 3).

In *downward* movement, with a sufficient discharge permitting erosion, characteristic *cross ripple-marks* appear, showing a real reaction of the stream-bed, as it were, against erosion (A, Fig. 3).

In *upward* movement, there is no erosion, no reaction by the bed, but a sedimentation process, shown by *parallel ripple-marks* normal to the current and due to a deficient discharge of the water, or at least to a lesser influx of water in that area.

FIG. 3. Patterns of erosional ripples. A, downward-going scour; B, upward-going scour.

4. Generally the areas of scour have a tendency at a given moment to alternate laterally in plan; a scour area will be followed downstream and part of the way across the stream by another such area and this in turn by another still further down and across the stream, giving a zig zag pattern. With the passage of time however, a given scour can likewise be seen to follow this zig zag path.

FIG. 4. Idealized representation of process. Heights are exaggerated. Areas of scour are black and deposition shaded. Arrow shows direction of flow.

5. A shift of concentration of heavy minerals follows the shift of the scours. A relationship similar to that shown by Fig. 4 is to be expected.

6. With a shift of scours, the longitudinal distances between these become greater.

7. It is strongly suggestive since the earlier experiments that the cycle of scours behaves on a *logarithmic pattern* in the distances separating the scours, as measured parallel to the axis of the trough, with the separating distances decreasing downward, as is well shown on the contour maps.

This logarithmic relationship between scours could be explained at first thought by the tendency of the profile of equilibrium of a river to be also a logarithmic curve and it would seem natural to connect the two phenomena.

8. A small concentration of heavy minerals seems to appear even before the actual appearance of the scour, *i.e.*, the latter cannot yet be seen but its effects are beginning to show.

The coming of a scour is generally foretold by the appearance of a preliminary leeward deposit of small specks of heavy minerals (mostly biotite) growing more and more numerous. In fact, very minute particles of sand have already been carried away by that time. The first effects to the eye only, by the color of the dark minerals, are readily followed by particles of sand being swept away a little upstream, then slowly gouging out the erosion area. This is a zone of higher velocity of current shown by a greater "cutting power" of the water.

Once originated, the scour becomes deeper and eddies are formed, growing more numerous. These lift the sand particles first, in a whirlpool, literally separating them from the heavy minerals and carrying them down stream rapidly, simulating the motion of an ore-dressing jig. The heavy minerals are lifted later on and are gradually deposited on the margins of the scour, then

FIG. 5. Characteristic pattern occurring downstream from an eddie.

progressively pushed downward in a distinctive and more or less elongated pattern (Fig. 5), showing a rhythmic action, progressively decreasing in intensity and affecting particularly the heaviest minerals.

Such a pattern may maintain itself for a time, new material regularly replacing the ones carried away by a rhythmic wave action. Then sometimes a large influx of water suddenly carries the heavy minerals away, totally or partially. If the scour ceases to be active, the pattern remains, unless buried later on.

9. In addition to the deposition downstream from the scour area, there often exists some deposition on the sides of that area and left where overflow or changes of the course of the river occur. This is analogous to the formation of natural levees or perhaps to alluvial terrace deposition.

10. The areal extent of heavy mineral deposition seems to be a function of the steepness of the slope down into the scour (as measured in a vertical section cut through the longest or the longitudinal axis of the scour) and of the gentleness of the slope downstream which leads up out of the scour.

Along the sides of the trough are often seen subparallel and oblique ripple marks in the sand surface called "rollers" by previous experimentators. These sometimes seem to play an important part in the distribution of the concentrates. In order to reduce these effects, a trough 3 or 4 feet wide, in place of the narrower width, with the corners rounded by a layer of clay would be more nearly ideal in order to avoid the interference of the walls.

11. The shorter the long axis of the scour, and the shallower the scour depression, the more localized the mineralization, and vice versa.

12. Two entirely different cycles of scours may show simultaneously as in Fig. 6. They were differentiated as: (1) Cycle C_{n-1} of "dead" scours, sometimes still showing, sometimes buried by sediments. Although buried, the location of such "dead" scours was carefully recorded during the last phase of the experiment. (2) Cycle C_n, or the last one, composed of all active scours. Here effective erosion continued until the water was turned off.

13. Going downstream, the scours show generally three marked changes: they become more and more elongated, they become less and less deep and are less and less followed by concentration of heavy minerals.

14. A greater slope makes the erosion areas change faster, and in the 5 minutes intervals of the record, many changes already occurred.

The contour maps show graphically the distribution of the erosion areas and are thus self-explanatory.

The concentration of heavy minerals, considered here as a surface deposit, is partly biotite and other dark minerals originally present in the quartzose sand, and partly magnetite. Of course only the surface deposit is recorded on the contour map and the surface alone does not give a complete picture of the whole process in which the magnetite is involved, because only two dimensions represented on the surface at a given time can be seen. A study of the concentration at depth is thus needed.

The results of each experiment were interpreted and the extent of each scour plotted on logarithmic paper. If the results show logarithmic relation,

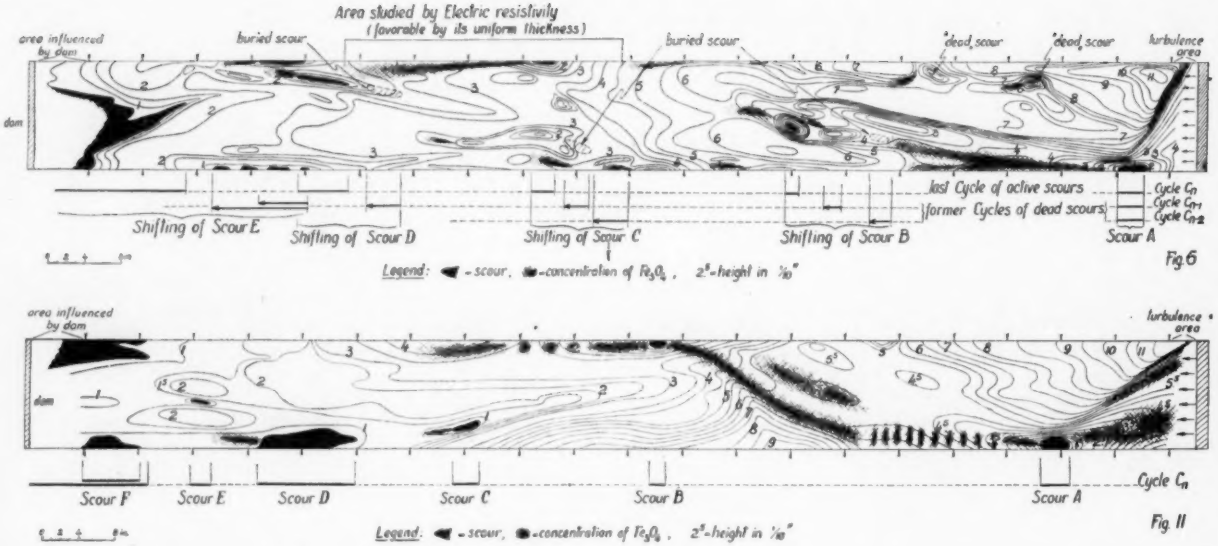

FIG. 6. Typical experiment.
FIG. 11. Experiment considered in detail (see Figs. 12, 13, and 14).

a curve would show on a semi-logarithmic graph and a straight line would be present on a log-log paper.

To develop a reasonably acceptable curve, at least 4 scours would be desirable and 5 would be preferable. Very probably with a longer trough, more scours would be available and this would permit a more dependable confirmation of any deductions arrived at.

Relationship at Depth.

Up to this point, the concentration observed was only a surface phenomenon. For a correct interpretation, it was necessary also to determine the concentration at depth that would give results more comparable to what is found in nature in alluvial deposits.

1. One approach to the study of concentration at depth was made by a simple section cut laterally into the bed of sediments (Fig. 7). Different layers of magnetite are neatly shown and they alternate in time just as did the scour at the surface. It was thus possible to interpret the lateral variations of the layers in time with the data recorded during the feeding period.

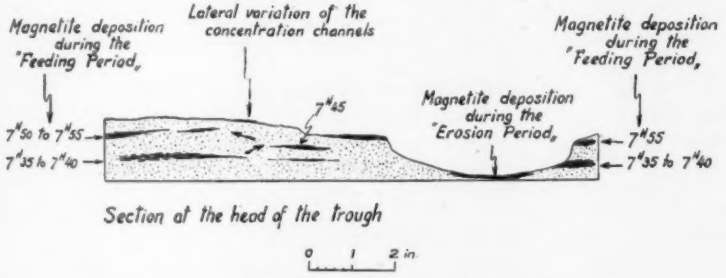
Magnetite deposition during the "Feeding Period"
Lateral variation of the concentration channels
Magnetite deposition during the "Feeding Period"
7"45
Magnetite deposition during the "Erosion Period"
7"50 to 7"55
7"35 to 7"40
7"55
7"35 to 7"40
Section at the head of the trough
0 1 2 in.

FIG. 7. Section showing concentration at depth.

2. A magnetic method was naturally sought for a check but as the areas involved were too small, an electric method was preferred, and a radio-tester used, the electrodes of which would give the resistivity of magnetite compared to that of the sand.

The electrodes of the radio-tester were kept half an inch apart and placed into the sand regularly at intervals of an inch, at the very spots where the depths were previously measured for the contour map. Figure 8 shows the results for Scour C with units of 500 megohms, and the areas of concentration, characterized by a lower resistivity, are clearly shown leeward of each scour with a decreasing ration in magnetite. It can be seen furthermore, not only that the last scour (active when the experiment stopped) is followed by this concentration, but even the former or "dead" scours, some of which have already been buried by subsequent sedimentation.

There is thus a shift of the concentration of the heavy minerals at depth, going along with the shift of scours, and as the scours move sometimes laterally, a part of the heavy minerals lag behind when the scour moves downward. It can be noticed that the three "generations" of scours in C are each affected by a concentration of magnetite, derived from them, and that these concentration zones often overlap.

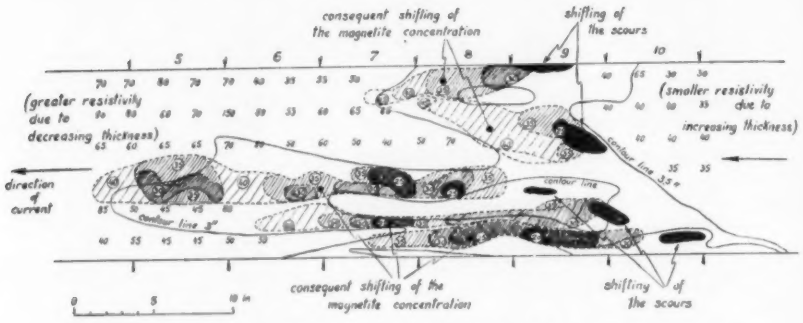
consequent shifting of the magnetite concentration
shifting of the scours
(greater resistivity due to decreasing thickness)
(smaller resistivity due to increasing thickness)
direction of current
contour line 3"
contour line 3.5"
consequent shifting of the magnetite concentration
shifting of the scours
0 5 10 in

FIG. 8. Study of the magnetite concentration at depth by electrical resistivity.

The scour C_{n-1} (older than C_n and already buried by sediments) shows a more restricted area overlapping partly the oldest one recorded, or C_{n-2}. Scour C_{n-2} is followed by heavy concentration because of its longer activity, as shown by its depression, still existing at the close of the experiment.

15. The concentration of heavy minerals at depth occurs thus leeward of the scours but with the continual shifting of the latter, these concentration areas overlap each other in vertical section.

The Logarithmic Relation of the Erosion Areas.

The contour maps illustrating the experiments were studied on the basis of the occurrence of the scours: (1) in space (*i.e.*, longitudinally) and (2) in time (*i.e.*, at depth) whenever possible, by a study of the "dead scours" or former ones as well as of the active and actual ones.

For this purpose, each contour map was supplemented with a longitudinal graph showing, in one or more distinct cycles in time, the distribution of all the erosion areas. The graph is self-explanatory and establishes a definite relationship of these areas: (1) in space: they become less and less distant and generally longer downward, (2) in time: they progress downstream (Fig. 6).

These graphs were the basis for a computation on logarithmic paper. With the order of scours along the ordinate and their length (taken from an origin at the lower end of the trough) along the abscissae, the different "generations" of scours could be plotted. Curved lines on simple log paper and straight lines on log-log paper definitely establishes a logarithmic relationship.

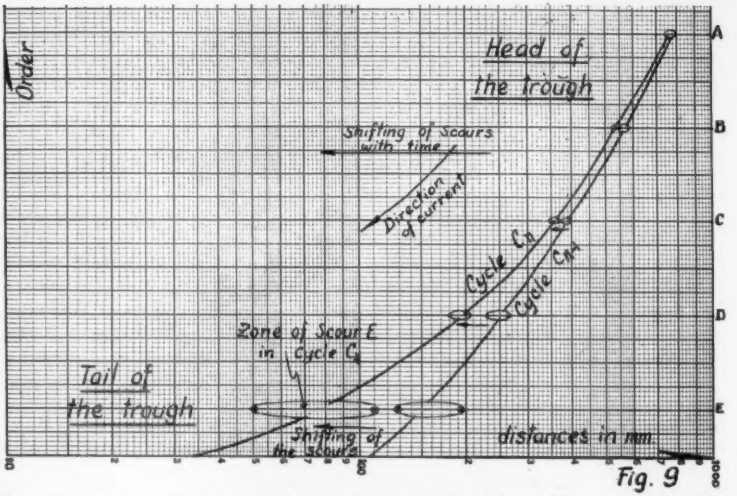

FIG. 9. Semi-logarithmic graph showing the relationship of the scours in time (different cycles) and in space (along the trough).

Moreover it can be said that the angle α of the representative line of scours (Fig. 10) appears to decrease in time, or in other words that the continual downward shift of scours causes the gradient of the line to decrease. Thus an older stage in a river would very probably show up with a larger gradient whereas a younger stage would be represented on the graph by a more steeply inclined straight line.

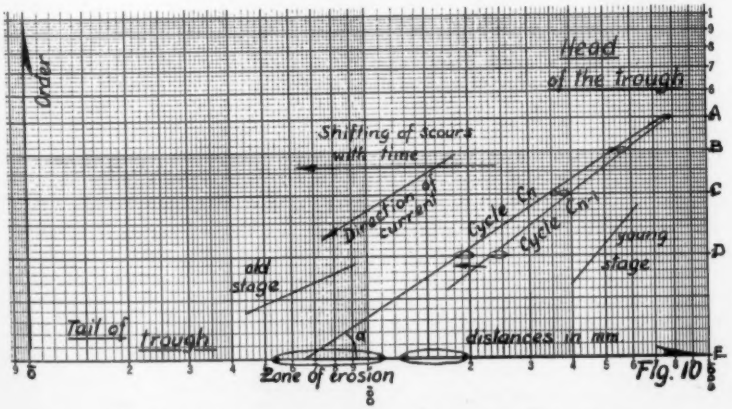

FIG. 10. Logarithmic graph showing same relationship.

FIELD DATA.

Ten more or less ideal cases, of which only one is presented here, were taken from actual maps to check the results acquired from the laboratory work. Individual rivers, were chosen where possible without any large tributaries in order to avoid the influence of, and the interference by, other cycles. A logarithmic graph (log-log) was made for each of them. All the ten cases show the same logarithmic relationship. It is admitted at the outset that the experiments and cases considered are not sufficiently numerous to give certainty, but the law they represent cannot be accidental.

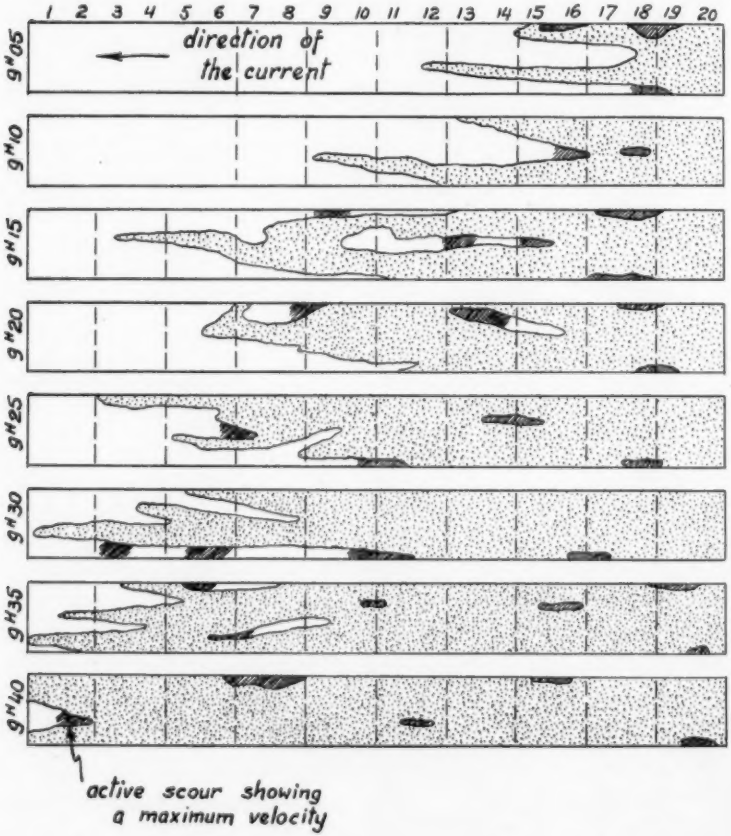

FIG. 12. Feeding period with the consequent positions of the scours (shown at 5 minutes interval).

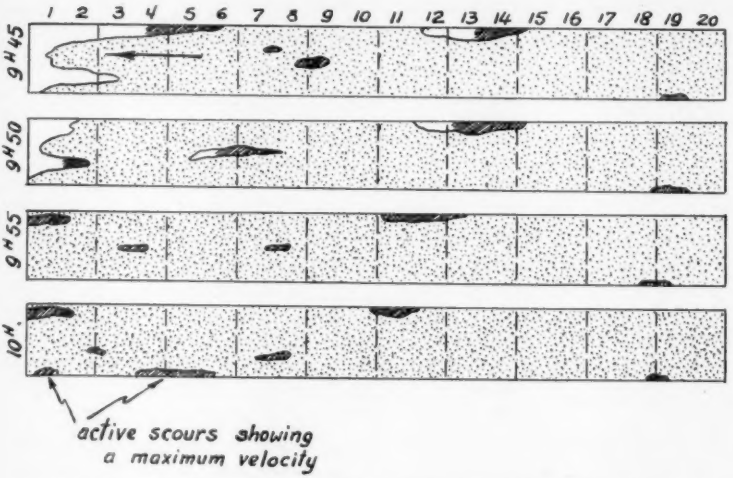

FIG. 13. Erosion period with the consequent positions of the scours.

Some practical observations taken from personal experience with placers in the Belgian Congo may be pointed out. Two different kinds of areas were generally noted along a single placer river, without suspicion at the time of their alternate nature.

1. Areas of erosion. These show only slight overburden generally consisting of dark soil, with unconsolidated water-washed gravel, which is generally well rounded, white in color, and rich in placer concentration. The total thickness (overburden + gravel) is apparently not of consequence; it is generally from 1 to 5 feet. Black humus, wet and swampy, is found on the margins of such areas and sometimes over them. The bedrock itself rarely appears at the surface. The surface of the ground coincides with the water table.

2. Areas of deposition. These show much overburden and generally small amounts of gravel, the whole being more consolidated, interlocked, and composed of sandy, clayey, and oxidized sediments making the digging and panning more difficult. The color of the gravel is brown as is also the overburden. No large ore concentration, if any, occurs. The thickness ranges from 4 to 15 feet, and more. Gravel may even be absent or it may grade into overburden. The surface of the ground is generally dry and above the water table.

Furthermore, detailed placer maps showing the zones of placer concentration along a river, very often indicate that the concentration occurs as patches, *i.e.*, as an *alternation* of ore-bearing gravel and barren gravel.

The areas of erosion and deposition of sand, in the experiments reported above, are similar respectively to the areas of ore-bearing gravel and barren

gravel. This coincidence shows a remarkable similarity between the laboratory data and the field data in the following three ways:

1. Areas of deposition (of sand) alternate with areas of erosion.
2. Concentration is related in the same way to the erosion zone.
3. The concentration areas are logarithmic in their distribution.

As the placer maps generally show the entire concentration zones (*i.e.*, everything above a certain economic "cut-off") the placer deposits of high ore-content cannot be regarded as perfect examples of the principles of concentration because the areas of ore-concentration as plotted on such maps are not sufficiently discriminating; such areas will connect with each other. If however, the rich deposits have records of the actual percentage of ore in them, and thus indicating the peaks of concentration, they then are excellent for comparison.

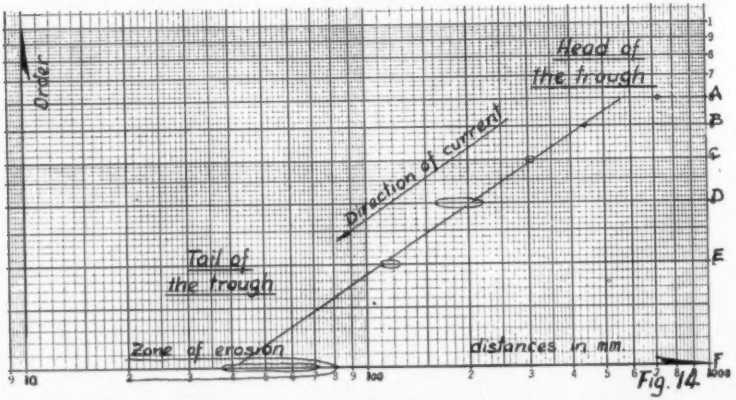

FIG. 14. Logarithmic graph showing the relationship of the scours.

Some assumptions have to be made in such a field study. It must be assumed that only one lode furnished the gravel; otherwise high and low areas of concentration may be distributed each with respect to its own lode. It must also be assumed that there is no mineralized tributary for the same reason. Further, it must be assumed in a given occurrence that might illustrate the principles here developed, that there is no special geological interference, such as falls or faults. Such features might disrupt the erosion process or the concentration frequency. Finally it must be assumed that there is no contact that could cause the development of a placer concentration from another lode. In this connection, reference is made to Brooks' statement: "the richest placers, except when there has been secondary concentration, occur at the contact of limestone and schists." [1]

[1] Brooks, A. H., Gold placers of Seward Peninsula, Alaska: U. S. Geol. Survey, Bull. 588, p. 291, 1908.

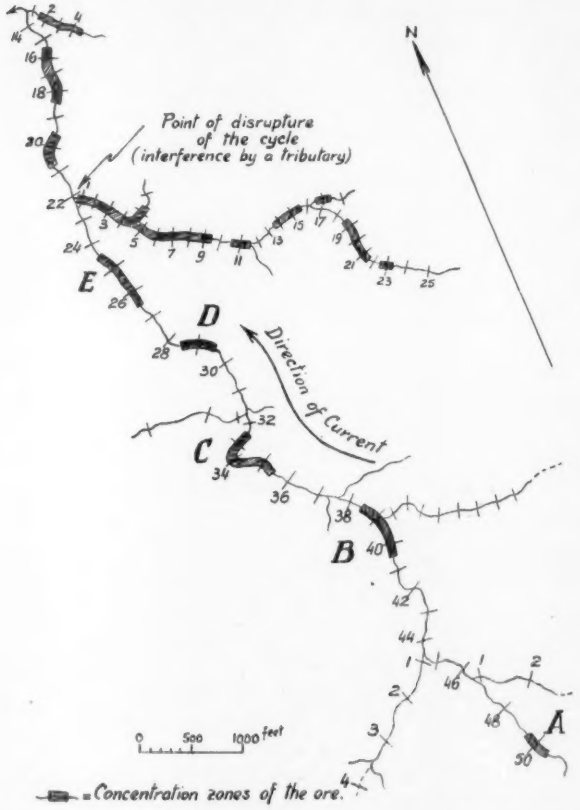

FIG. 15. Typical example of the logarithmic distribution of the concentration zones in an actual case (in a placer mining district in the Eastern Belgian Congo).

The first zone of concentration and erosion upstream apparently coincides with the "break of the slope" of the river, generally called the "natural riffle," and known for its deeper erosion and for its outstanding concentration power. This is the place that is sought in placer reconnaissance.

PRACTICAL APPLICATIONS.

Although insufficient time has elapsed to determine how this theoretical study may be applied in the field, two different possibilities already suggest themselves.

The principles developed can first be applied in the search for areas of placer concentration. The erosion zones can be located in the field by finding the places of greatest water velocity and their relation to the bed-rock (Fig. 17 A). The one farthest upstream will probably occur at the break of the slope, and the others will follow in logarithmic sequence. Three may even be sufficient information for the deductions of other ones downstream, if there is no interference factor.

The cycle being known and plotted, the concentration areas are to be found around the "erosion centers," probably being more extended above them and on the whole more elongated longitudinally downstream (Fig. 17 B). Taking in account the width of the stream, these areas are likely to be more laterally widespread going downstream (Fig. 17 C), with however definite pay-streak zones in them.

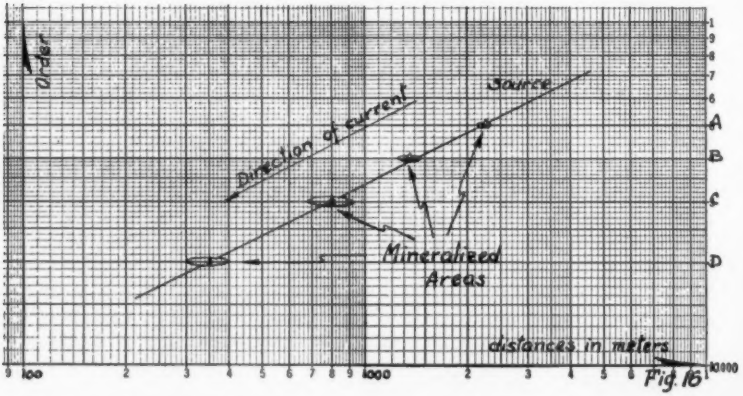

FIG. 16. Logarithmic graph corresponding to the Field Case of Fig. 15 (the centers of the mineralized areas (△) have been taken as an approximate representation of the centers of the erosion zones.—The origin is undefined due to the interference of a mineralized tributary).

These areas also become poorer downstream, with more divided and finer ore (Fig. 17 D). However, because of their large volume they may be very productive under large-scale mechanical placer mining methods. Finally, there are alternately rich (a) and barren (b) zones in a definite order and with definite characteristics (Fig. 17 E).

Due allowance, however, must be made for tributaries, the presence of more than one lode, special geologic, topographic, and geomorphological features, and placer-bearing benches or terraces.

On the other hand, if reasonably accurate placer maps are available, it would be possible at a glance to check the regularity of the trend of ore concentration. It should be possible also to check the quality of a prospect.

Furthermore, the interpretation of placer maps becomes easier because it can be made on a sounder basis. The placer concentration zones can now be considered as definitely spaced with a relatively barren hiatus between each pair of concentration zones. This point, once ascertained and explained, appears no longer questionable. Naturally the topographic features may enter into the picture.

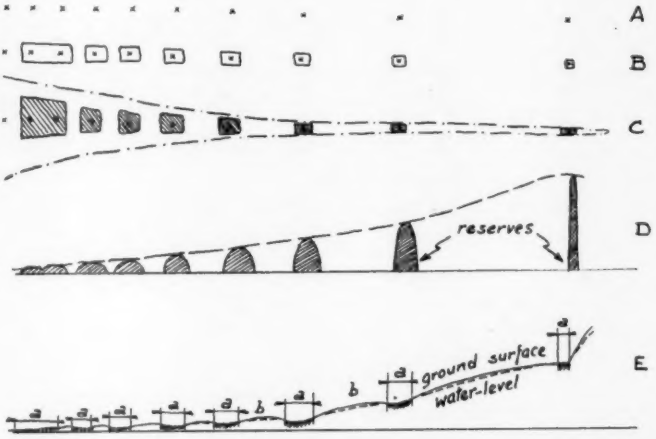

FIG. 17. Résumé about the search of areas of placer concentration in a river. A. Erosion centers (of maximum velocity of the water) in plan. B. Concentration areas in plan. C. Location of these areas in the valley (map). D. Graph showing the theoretical distribution of the reserves (tenor per cubic unit in ordinates and volume of ore in abscissae). E. Profile of the river with its alternation of rich and barren zones, and the position of the water-level.

In areas of longitudinally widespread placer concentration, where the different areas are connected, the peaks of highest concentration are needed, especially for the lower parts of the stream, to permit a true identification of the logarithmic pattern and of its crests and troughs.

With these principles in mind, a study of placer maps facilitates vizualization of the whole process of concentration. Thus, some light is shed upon the localization and distribution of these concentration areas. If irregularities happen to exist, the presence of interference factors can justifiably be anticipated.

DEPARTMENT OF GEOLOGY,
COLUMBIA UNIVERSITY,
NEW YORK,
Nov. 29, 1948.

THE DIFFERENTIATION OF TITANIFEROUS MAGMAS.

PIERRE EVRARD.

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ABSTRACT.

This paper summarizes first the results of a former study in which it was pointed out that a statistical relation existed, during the differentiation and solidification of the magma, between the three oxides TiO_2, Fe_2O_3 and FeO, contained in rocks and in titaniferous ores from the Adirondack Mountains. In the above magmas, the oxidation in the different rocks decreases as the differentiation proceeds and is at a minimum for the gabbroic rocks associated with the titaniferous ores. On the contrary, the ores seem to have a high oxidation index. This fact is in agreement with the evolution of residual solutions with which ores are in direct connection. The relations between gabbroic rocks and ores are discussed in detail. It is concluded that the TiO_2 concentration of ores is limited to about 30 percent (molecular percentage) relative to the total $TiO_2 + Fe_2O_3 + FeO$ mols (computed to 100 percent).

The probability of a eutectic is discussed and its composition quantitatively fixed. This fact is checked and emphasized by the comparison of analyses of rocks and ores from the Adirondacks with many analyses of ores from other regions.

INTRODUCTION.

The Eruptive Massif of the Adirondacks.—The Adirondack Mountains of New York State have had their geological features well defined by Buddington (Fig. 1). Therefore, I shall give, for the classification of petrographic massifs, the nomenclature as it was offered in the outstanding memoir of this author (15).[1]

Chronologically, from the oldest to the youngest, Buddington distinguished the following formations:

[1] Numbers in parentheses refer to Bibliography at end of paper.

A. The most ancient rocks in this region which belong to the Grenville series (sedimentary material strongly metamorphosed): crystalline schist, gneiss, marbles, quartzites, skarn, etc.

B. I. The anorthositic series which represent the first widely developed intrusion. Locally, one can observe series with similar order and composition: anorthosites and anorthositic gabbro, very mafic gabbros, apatite-rich gabbros with ilmenite-magnetite. The segregations occur in concordant layers, and also in dikes. All the rocks of this series belong to the *saturated type*. In the main mass there are primary zonage and flowage structures, particularly in the border facies. The primary magma that produced the anorthositic complex is supposed to have had the composition of a gabbroic anorthosite.

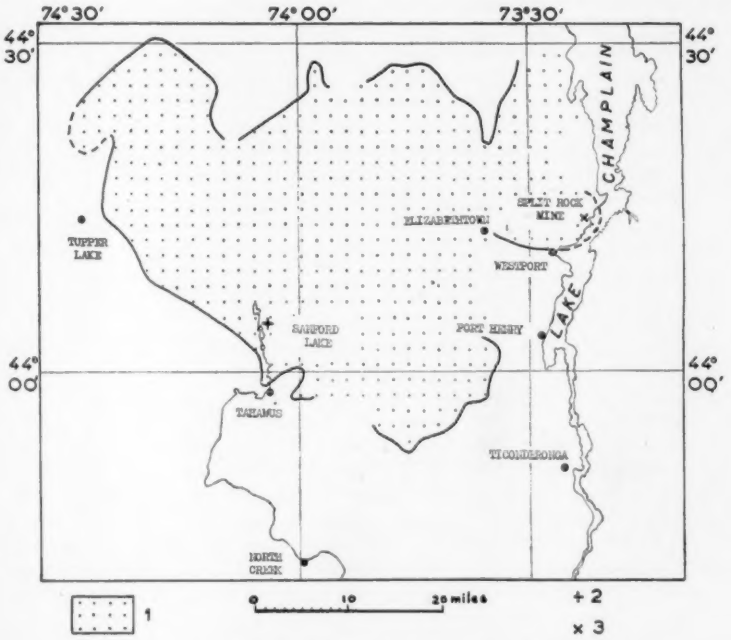

FIG. 1. Geological schematic map of the Adirondack District.
Explanation: 1. Area underlain by gabbroic anorthositic rocks. 2. Sanford Lake deposits. 3. Split Rock Mountain deposits. (Adapted from A. F. Buddington (15), reproduced from J. R. Balsley Jr. (6).)

II. Then come the basic gabbros, formerly considered younger than the syenite-granite series and now described as younger than the anorthositic rocks but older than the syenite-granite complex. These gabbros intrude the Grenville series and anorthosites; they also occur in concordant layers. Their com-

position is that of an olivine-gabbro. They are *undersaturated*. They occur throughout the Adirondack Mountains but their mass is much less important than that of the anorthositic rocks and the younger quartz, syenites and granites. In metagabbro masses adjacent to anorthositic bodies, there are bands of mafic metagabbro in places rich in ilmenite-magnetite.

III. Still younger are a series of dioritic rocks (Rossie series) found in intrusive sills or laccoliths; they are younger than the gabbros and older than the syenitic complex.

C. The next magmatic age is characterized by the intrusion of a magma that probably had the composition of a pyroxene-quartz syenite.

Among those magmatic series from the Adirondacks, I have restricted my study to the eruptive complex associated with ilmenite and magnetite ores. Therefore only the intrusions that belong to the groups defined above are considered, B. I and B. II.

B. I. The rocks that were derived from a saturated magma, the original composition of which is approaching that of a gabbroic anorthosite; by differentiation this saturated magma has yielded:

(a) anorthosites, in the central part of the massif,
(b) anorthosites of another facies, in the border part of the massif,
(c) late differentiations having a gabbroic character,
(d) titaniferous ores of Lake Sanford type.

B. II. The rocks that were derived from an undersaturated magma, the original composition of which is comparable with that of an olivine-gabbro. To this group belong the following series:

(a) basic metagabbros in the northwestern Adirondacks,
(b) basic metagabbros in the eastern Adirondacks,
(c) a special metagabbro type, intermediate between a rock and an ore; it contains about 30 percent opaque elements,
(d) titaniferous ores of Split Rock Mine type.

Preceding and Present Results.—In a recent publication (21) I have pointed out that rocks and ores growing during the differentiation of both titaniferous magmas, B. I and B. II above, have a chemical composition that is not distinctive. The solidified products successively formed during the differentiation process contain by weight-unit a constantly growing number of $TiO_2 + Fe_2O_3 + FeO$ mols. It was also shown that the average values of the TiO_2 mol number and of the $TiO_2 + Fe_2O_3 + FeO$ mol number, computed for each typical differentiated stage, verify a rule of the following form:

$$N_{TiO_2} = a \cdot N^k{}_{TiO_2+Fe_2O_3+FeO}$$

in which N = mol number of the oxides ascribed as index, by weight unit of rock or ore; a and k = two parameters, different for each magmatic entity but constant for all the differentiated stages of a same magma.

Established statistically, using many petrographical and chemical data from Buddington's memoir and other studies, this rule characterizes a magmatic entity and specifies for derived rocks and ores the evolution and general tendency with regard to absolute and relative quantities of the different oxides contained in these rocks and ores: TiO_2, Fe_2O_3, FeO.

Having shown what, during crystallization, are the modifications of the ratios between Fe_2O_3 and FeO, I shall next synthesize the connections in composition that exist, in the final stage of differentiation, between gabbroic rocks and ores intimately and genetically bound together. I shall also attempt to show that the hypotheses set forth are not confined to the Adirondack ore bodies alone, but have a more general character.

EVOLUTION OF THE RATIO Fe_2O_3 : FeO.

From the analyses cited and characteristic of each quoted petrographical category, *i.e.* B. I a, b, c, d, and B. II a, b, c, d, I have computed the average ratio:

$$A \equiv \frac{Fe_2O_3}{Fe_2O_3 + FeO} \qquad \text{and} \qquad B \equiv \frac{TiO_2}{TiO_2 + Fe_2O_3 + FeO}$$

Table I, below, and Figure 2 summarize the numerical data.

TABLE I.[2]

Analyses No.	Rock categories	Signs on fig. 2	A in %	B in %
57, 58	I. a	1	14.90	15.35
59, 60, 61	I. b	2	10.45	16.95
62	I. c	3	7.60	18.60
66 and 112 to 124	I. d	4	28.10	22.30
79 to 86	II. a	1'	11.50	10.80
87 to 95	II b	2'	7.10	14.40
96	II. c	3'	13.02	22.80
97 to 100 and 105 to 111	II. d	4'	31.60	24.40

Discussion.—The ratio TiO_2 : $TiO_2 + Fe_2O_3 + FeO$ has been chosen as the variable along the abscissa because this ratio grows continuously and regularly in each successive differentiated stage.[3]

The second ratio Fe_2O_3 : $FeO + Fe_2O_3$ has been chosen to define the oxidation conditions of solid products "born" of each magma. Therefore, both lines (I and II) on Figure 2 actually represent the variation of the oxidation station of the solid products during the differentiation process.

The low points (2' and 3) divide the diagrams into two distinct zones: the first one (left) corresponds to a period during which the ratio Fe_2O_3 : Fe_2O_3 + FeO falls; the second one (right) corresponds to a period during which the same ratio is increasing.

It is noted that the ratio Fe_2O_3 : Fe_2O_3 + FeO falls respectively down to 7.6 percent and 7.1 percent in rocks with gabbroic character belonging to both saturated and undersaturated types. The first part of each broken line con-

[2] See Figure 2.
[3] This is a conclusion of my former study.

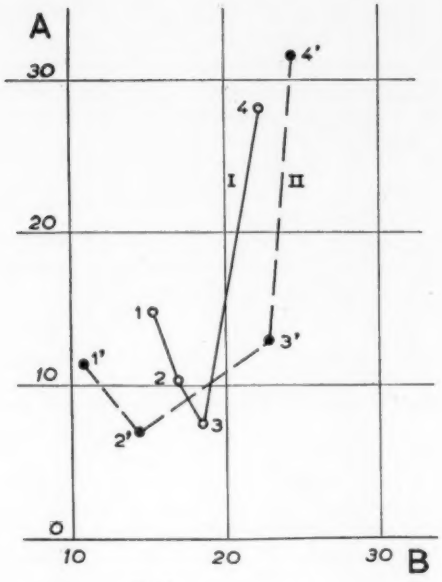

FIG. 2. $A = \frac{Fe_2O_3}{Fe_2O_3 + FeO}$ (in mol percentage).

$B = \frac{TiO_2}{TiO_2 + Fe_2O_3 + FeO}$ (in mol percentage).

cerns analyses of rocks, *i.e.* mineralogical associations in which silicate minerals predominate that are transparent in thin sections.[4]

On the other hand, an important increase of the ratio $Fe_2O_3 : Fe_2O_3 + FeO$ is noted in ores, aggregates with predominant oxide segregations and in the rock (analysis No. 96), which contains a particularly important percentage of opaque minerals (30 percent). From these remarks, one can infer that, during the differentiation, there exists a general tendency towards a decrease of the oxidized state in the solid products of the magma. This state is fixed, as said before, by the ratio $Fe_2O_3 : Fe_2O_3 + FeO$ obtained by chemical analyses of rocks characteristic of successive solidified stages. This tendency undergoes an abrupt reverse for the value of the same ratio in ores of final differentiated stages. Is it possible to account for this process, pointed out by the fact of the minimum, considering the geological observations?

[4] The use of the terms "rock" and "ore" is likely to raise a discussion about the meaning of these words. Where is the boundary between one category and the other? Upon what criteria must this definition be grounded? I prefer not to open here this subject and keep to the practical acceptation.

First of all, there is continuity in the differentiation from anorthosite to ores, passing through the gabbroic facies. The late character of the titaniferous magma crystallization, with regard to the magmatic associated rocks, is now admitted by all geologists. Since, during the last differentiation stages the content of opaque minerals in the gabbroic rocks progressively increases, and sometimes in large proportions, the intermediate position of point 3′ (analysis No. 96) is easily understood. This association possesses the characteristics of both rocks and ores. Of course, the "oxidation ratio" computed for this last case tends to approach the ratio obtained for ores, owing to the high percentage of oxides in this rock. It is difficult, in the present state of knowledge, to determine this bottom question, *i.e.* to explain why the aggregates of different minerals, mixed together to make up a rock, offer, when analyzed as a whole, a ratio $Fe_2O_3 : Fe_2O_3 + FeO$ that decreases in each of the successive solid stages. However, this observation is to be noted: the evolution of these solid stages seems to be opposite to that of the remaining solutions.

Referring to the physico-chemical data, one may attempt to rebuild the probable evolution of the residual solution. Indeed one knows the existence, among the volcanic emanations of basic magmas, of CO_2, H_2O, SO_2, etc., in great quantities. At high temperature, in the magma, these fluids are associated with metallic oxides and, in the liquid phase, they may react with one another. Thus, the equilibria cited below will have a great influence on the composition of the liquid phase during its cooling:

$$FeO \cdot Fe_2O_3 + H_2 \rightleftharpoons 3FeO + H_2O$$
$$FeO \cdot Fe_2O_3 + CO \rightleftharpoons 3FeO + CO_2$$

In these equilibria, pressure does not interfere since the reactions happen without any change of volume; they move to the left when the temperature is lowered. Therefore, during the cooling, as soon as the crystallization temperature of silicates is reached, the residual solutions on the one hand will contain a larger and larger percentage of ferric iron with regard to ferrous iron; the solid phase on the other hand, as indicated by the figures quoted, will be minerals that, all together, absorb a larger and larger proportion of ferrous iron relative to ferric iron. Moreover, either in the solid or in the fluid state, the molecular concentration of titanium and iron oxides continuously increases.

It is clear that one can propose only hypotheses concerning the composition of the successive fluid phases that were in equilibrium with the corresponding solid phases. The latter only remain, and when one knows the relative age of the solid states, one can establish the changes in the chemical composition of these states with regard to the various differentiation stages. As for the fluid phase, one can set forth an hypothesis provided the physico-chemical laws are taken in consideration. Then, it is possible to verify the concordance of the consequence of this hypothesis with the observed geological occurrences.

I have applied that method in this study. The field-observations of Buddington show that titaniferous ores have accompanied or followed the crystallization of gabbroic rocks, *i.e.* those that have a minimum oxidation index. On the other hand, the ores born from residual juices offer a much higher oxi-

dation index, as may be seen in Figure 2. The high index is explained by the oxidizing action of H_2O and CO_2, which at the last stage can become important owing to the continuous decrease of temperature. If it must be admitted that absolute quantities of FeO and Fe_2O_3, combined into usual basic rock minerals, increase during the differentiation, it seems that Fe_2O_3 shows less ability than FeO to enter in the same associations. Indeed Fe_2O_3 is concentrated in the residual solutions where it is combined with the surplus FeO and TiO_2 to constitute the essential minerals of the titaniferous ores, magnetite and ilmenite.

In order to explain the lowering of the ratio $Fe_2O_3 : Fe_2O_3 + FeO$ in the rocks, as differentiation proceeds, some hypotheses must be offered.

The first one and the most simple would be to admit that great quantities of minerals with Fe_2O_3 as chief constituent crystallized during the first stages. This would result in magmatic phases poorer and poorer in Fe_2O_3. This hypothesis does not stand since one could not explain the presence, in the residual juices, of important Fe_2O_3 masses which combine with TiO_2 and FeO to constitute the ores. Moreover, petrographic investigations show that FeO-rich minerals (such as pyroxenes, amphiboles, etc.) and Fe_2O_3-poor minerals crystallize first in anorthosites and gabbros of the Adirondacks. In any case, they solidify before the opaque minerals, the crystallization order of which has already been pointed out.

A second hypothesis might postulate that the Fe_2O_3 concentration took place from the beginning of the differentiation process in a distinct oxide-rich fusion. This involves the association of these oxides with the late gabbroic products since the ores are with gabbroidal rocks and not with anorthositic ones. But this hypothesis alone is not sufficient. I think it necessary to imply other phenomena, for instance reduction and oxidation processes during the differentiation. The causes of these must be searched for, as mentioned before, in the variations of chemical equilibria that accompany the magma crystallization.

Nevertheless, and independently of the hypotheses set forth, it is to be noted that the differentiation must have proceeded to a certain degree before titaniferous ores can form, since they occur later than the solidification of gabbroic rock minerals. They are characterized by a minimum oxidation index so that this index becomes a measure of the chemical conditions of the magmatic stage that often precedes and sometimes accompanies the concentration of the oxides: TiO_2, Fe_2O_3 and FeO. Thus, this minimum oxidation of gabbroic rocks seems to provide the proper conditions for the genesis of titaniferous magnetite ores.

One must not overlook the fact that the physico-chemical evolution during the magmatic differentiation process has been sketched upon the basis of average chemical compositions of different groups of rocks and ores. If, in one of these groups, the evolution of the equilibrium is studied, comparing the chemical compositions of the group terms, it may happen that the law would not be exactly the same as that established for the averages of every series. In other words, the detailed evolution of one group may be different from that of the averages of the four groups. I shall attempt further to define this point more clearly.

CONNECTIONS BETWEEN ORES AND GABBROIC ROCKS.

At the beginning of this section, I think I must insist on the differences between the principles on which the preceding part of this study is grounded and those upon which the following sections will be based.

In the preceding discussion I have expressed some views about the connection between the quantities of TiO_2, Fe_2O_3 and FeO contained in eruptive rocks and ores. For this discussion I have used computed averages of whole chemical analyses. Rock and ore standards have been defined according to geological and petrographical considerations, as set forth by Buddington. Each set is characteristic of a stage among the principal groups that are distinguished in each saturated and undersaturated series that belong to both ancient eruptive Adirondack entities. So far, I have considered absolute quantities of oxides and oxidation ratio variations in different sets of magmatic solid products.

I shall now show other relative variations restricted to the oxides TiO_2, Fe_2O_3 and FeO, and shall undertake the question with respect to relative molecular amounts of the same oxides.

The same analytical data will serve again; they have been plotted on a ternary diagram (Fig. 3). On this scheme, one must distinguish, first, the dashed curves I and II that correspond to the first part of the lines I and II in Fig. 2. Points 1, 2, 3 and 1′, 2′, are defined in the same way on both diagrams. Point 3′ of Fig. 2 corresponds on Fig. 3 with the point of analysis No. 96. Point 3 represents the average for analyses Nos. 87 to 95. It is unnecessary to plot points 4 and 4′, averages for analyses of ore sets Nos. 66, 112 to 124, and Nos. 97 to 100, 105 to 111, as on this new scheme I do not intend to discuss them further.

The curves I and II and plotted points 1, 2, 3 and 1′, 2′ are drawn on Figure 3 in order to make it easier to read the text, and to allow an easier connection between the subjects here studied. The significance of the solid line of the diagram is developed below. It represents a set of gabbroic rock analyses and a set of ore analyses, the ores being closely related to the rocks. The composition relations in the groups of minerals gathered in the late magmatic stages can be easily derived.

Analytical data are complete for the amounts of TiO_2, Fe_2O_3 and FeO for metagabbros of the eastern Adirondacks (Nos. 87 to 95 and 96) as well as for Split Rock Mine type of ores (Nos. 97 to 100, 105 to 111) that are genetically related to these metagabbros. Each analysis is plotted on the ternary diagram Fig. 3 and so are the average curves (in solid lines) for rocks and ores. The two curve segments, one for the metagabbros, the other for ores, nearly exactly join points Nos. 95 and 96. This last one represents the rock exceptionally rich in opaque minerals.

The diagram does not represent "a priori" the differentiation of a magma and one can neither speak of it in the sense of the chemical evolution related to the crystallization sequence nor of the relative age of all these rocks, as field investigations have not afforded evidence to verify these questions. However, it is interesting to note that the relations between the three oxides TiO_2, Fe_2O_3 and FeO are not of random kind at stages of the solidification. On the con-

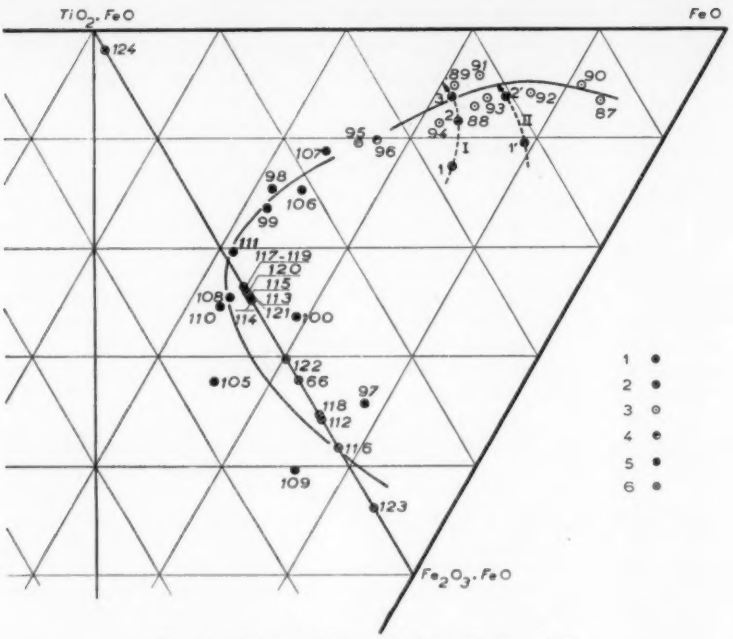

FIG. 3. Ternary diagram $TiO_2 - Fe_2O_3 - FeO$.

Explanation: 1. Average analyses of each group of rocks belonging to saturated intrusive series (I). 2. Average analyses of each group of rocks belonging to the undersaturated intrusive series (II). 3. Individual analyses of metagabbro from the eastern Adirondacks (analyses Nos. 87 to 95). 4. Intermediate rock, with 30% opaque elements (analysis No. 96). 5. Analyses of ores associated with rocks of undersaturated groups (Nos. 97 to 100 and 105 to 111). 6. Analyses of ores associated with rocks of saturated groups (Nos. 112 to 124).

tary, there is a "solution de continuité" and the joining is easily found between rocks and ores although the evolution of relative amounts shows reverse features. Therefore, I interrupted the curve that depicts the general average evolution and have drawn two separate segments, one for rocks, the other for ores.

In the ore series, when the relative percentage in TiO_2 increases, the ratio Fe_2O_3 : FeO decreases. For rocks, on the other hand, it increases. In other words, FeO and TiO_2 vary in the same direction when in ores and in opposite direction when in rocks. In ores, the ilmenite thus grows in importance together with TiO_2. If ratios do not obey the same rule in rocks as in ores, the explanation must be searched for in the mineralogical complexity of the associations of which they are composed. Titanium oxide is a constituent of nu-

merous transparent minerals such as augite, biotite, and others. In this case, TiO_2 may be combined after a different law than that which rules its behavior in the ores, as will be shown hereafter.

If one admits that the ratio Fe_2O_3 : FeO partly rules the rock mineralogy, then the mineralogy itself rules distribution and absorption of TiO_2 between the different mineral constituents. So indirectly there is a connection between

TABLE II.

LIST OF ANALYSES.

Rocks and ores of different origin.

No.	Weight percentages			Molecular numbers (×1000)			Molecular percentages		
	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO
1	23.80	36.00	32.60	298.0	226.0	454.0	30.60	23.10	46.3
2	2.77	61.73	31.75	35.0	387.0	442.0	4.0	44.8	51.2
3	41.50	20.46	36.29	520.0	128.0	505.0	45.1	11.1	43.8
4	41.75	22.11	31.01	522.0	138.0	431.0	48.0	12.7	39.3
5	39.20	18.59	30.0	490.0	116.0	417.0	48.0	11.3	40.7
6	34.50	29.00	27.00	431.0	181.0	375.0	43.65	18.35	38.0
7	45.77	14.10	39.50	572.0	88.0	548.0	47.3	7.3	45.4
8	41.96	22.22	31.16	525.0	139.0	433.0	47.8	12.7	39.5
9	45.93	14.30	36.52	575.0	89.4	507.0	49.2	7.6	43.2
10'	11.54	56.56	25.80	144.0	348.0	358.0	14.2	34.2	51.6
			6.80[1]			168.0			
12'	53.21	11.90	27.99	665.0	74.3	389.0	50.8	5.7	43.5
			7.20[1]			178.0			
13	43.4	19.3	34.7	543.0	120.7	482.0	47.5	10.5	42.0
14	40.0	20.35	29.57	500.0	127.0	411.0	48.2	12.2	39.6
15	22.42	31.15	36.91	282.0	195.0	511.0	28.6	19.7	51.7
17	23.49	45.03	17.96	294.0	273.0	250.0	36.0	33.4	30.6
18	4.95	54.42	30.28	62.0	340.0	421.0	7.5	41.3	51.2
19	**24.0**	**38.0**	**33.0**	300.0	238.0	459.0	30.0	24.0	46.0
20	8.25	**56.0**	**32.0**	103.0	350.0	445.0	11.5	38.9	49.6
21	43.12	**19.0**	**34.0**	540.0	119.0	473.0	47.7	10.6	41.7
22	15.35	41.95[2]		192.0	186.0	378.0	Il.: 50.8		M.: 49.2
23	1.27	67.60[2]		16.0	397.0	413.0	Il.: 3.9		M.: 96.1
24	16.20	21.63[2]		206.0	61.5	267.5	Il.: 77.0		M.: 23.0
25	23.18	48.97	24.55	290.0	306.0	340.5	31.0	32.6	36.4
26	22.43	47.21	25.80	280.0	295.0	358.0	30.1	31.6	38.3
32	15.70	53.8[2]		196.0	255.0	451.0	Il.: 43.5		M.: 56.5
33	13.29	52.1[2]		166.0	256.0	422.0	Il.: 39.2		M.: 60.8
34	13.08	51.75[2]		163.3	254.5	417.8	Il.: 39.2		M.: 60.8
35	11.26	51.25[2]		140.8	259.0	400.0	Il.: 35.2		M.: 64.8
36	10.82	50.85[2]		135.0	258.0	393.0	Il.: 34.4		M.: 65.6
37	9.72	51.12[2]		121.5	264.0	385.5	Il.: 31.6		M.: 68.4
38	26.12	28.39	42.81	327.0	177.0	595.0	29.75	16.10	54.15
39	10.28	12.71	35.12	128.0	79.0	488.0	18.4	11.5	70.1
41	13.50	56.44[2]		169.0	280.0	449.0	Il.: 37.8		M.: 62.2
42	13.50	58.68[2]		169.0	293.0	462.0	Il.: 36.8		M.: 63.2

[1] MgO amount; it was associated with FeO. The index, by the reference number means that the MgO percentage is taken into account.

[2] Fe total percentage. In this case, FeO is computed in order to saturate TiO_2. Remaining Fe is computed as Fe_3O_4. The molecular percentages are indicated with regard to Il. = ilmenite and M. = magnetite.

The analyses of a rock or an ore and those of their black mineral constituents are joined by brackets.

Bold figures are obtained by the interpretation of incomplete data.

TABLE II—Continued.

Rocks and ores from the Adirondacks.

Saturated Series (I).

No.	Weight percentages			Molecular numbers (×1000)			Molecular percentages		
	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO
(a) 57	0.43	0.75	1.59	5.38	4.69	22.10	16.7	14.6	68.7
58	0.24	0.35	1.24	3.0	2.19	17.25	13.35	9.75	76.9
(b) 59	1.12	1.31	3.89	14.0	8.2	54.0	18.4	10.7	70.9
60	0.77	0.91	3.02	9.65	5.69	41.9	16.9	9.95	73.15
61	0.92	0.66	4.17	11.5	4.13	57.9	15.6	5.6	78.8
(c) 62	2.54	1.69	9.27	31.8	10.6	129.0	18.5	6.2	75.3
(d) 66	13.38	59.56		167.0	300.0	467.0	Il.: 35.8	M.: 64.2	
112	10.73	63.45		134.0	333.0	467.0	Il.: 28.7	M.: 71.3	
113	19.74	53.62		246.5	237.0	484.0	Il.: 51.1	M.: 48.9	
114	20.24	55.62		252.5	247.5	500.0	Il.: 50.50	M.: 49.5	
115	20.49	54.80		256.0	242.0	498.0	Il.: 51.40	M.: 48.6	
116	8.25	62.15		103.0	336.0	439.0	Il.: 23.5	M.: 76.5	
117	15.77	40.33		197.0	175.0	372.0	Il.: 53.0	M.: 47.0	
118	10.91	62.65		136.0	328.0	464.0	Il.: 29.3	M.: 70.7	
119	20.03	51.22		250.0	222.0	472.0	Il.: 53.0	M.: 47.0	
120	19.52	51.30		244.0	225.0	469.0	Il.: 52.0	M.: 48.0	
121	18.7	51.44		234.0	229.0	463.0	Il.: 50.6	M.: 49.4	
122	14.52	56.60		181.5	277.0	458.5	Il.: 39.6	M.: 60.4	
123	4.0	62.66		50.0	357.0	407.0	Il.: 12.3	M.: 87.7	
124	47.5	36.86		593.0	22.0	615.0	Il.: 96.4	M.: 3.6	

[2] Same remark as (2) in the list of rocks and ores of different origin.

Under-saturated Series (II).

No.	Weight percentages			Molecular numbers (×1000)			Molecular percentages		
	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO
(a) 79	1.31	3.44	7.35	16.4	21.5	102.1	11.55	15.15	73.3
80	1.28	2.25	5.39	16.0	14.1	74.85	15.2	13.4	71.4
81	1.53	6.14	8.01	19.2	38.4	111.2	11.4	22.8	65.8
82	1.83	1.81	10.20	22.9	11.3	141.7	13.1	6.4	80.5
83	1.28	1.08	9.40	16.0	6.75	130.5	10.4	4.5	85.1
84	0.91	1.73	7.82	11.4	10.8	108.5	8.7	8.25	83.05
85	1.37	1.93	10.69	17.1	12.1	148.5	9.6	6.8	83.6
86	0.93	1.49	9.69	11.6	9.3	134.5	7.5	6.0	86.5
(b) 87	1.18	2.29	12.39	14.75	14.30	193.0	6.65	6.45	86.9
88	2.54	2.17	10.6	31.8	13.6	147.3	16.45	7.05	76.5
89	3.55	1.86	12.8	44.3	11.60	178.0	18.9	5.0	76.1
90	1.2	1.39	10.45	15.0	8.7	145.0	8.9	5.1	86.0
91	3.37	1.61	13.81	42.1	10.07	192.0	17.4	4.1	78.5
92	3.03	2.03	13.12	27.9	12.7	182.2	12.6	5.7	81.7
93	2.22	1.73	9.79	27.8	10.8	136.0	15.8	6.2	78.0
94	3.55	3.24	12.76	44.3	20.6	177.0	18.4	8.5	73.1
95	5.26	4.63	12.99	65.7	29.0	180.5	23.9	10.55	65.55
(c) 96	7.43	6.6	19.8	93.0	41.2	275.0	22.7	10.1	67.2

TABLE II—Continued.

Under-saturated Series (II) (continued).

No.	Weight percentages			Molecular numbers (×1000)			Molecular percentages		
	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO	TiO_2	Fe_2O_3	FeO
(d) 97	5.21	30.34	22.81	65.0	190.0	303.0	11.6	34.2	54.2
98	15.66	15.85	27.94	195.8	99.0	388.0	28.7	14.5	56.8
99	16.45	20.35	28.82	206.0	127.0	400.0	28.1	17.3	54.6
100	12.31	30.68	27.92	154.0	192.0	388.0	21.0	26.2	52.8
105	14.7	38.43	23.4	183.7	242.0	325.0	24.4	32.2	43.4
106	10.55	11.52	21.34	131.9	72.9	296.0	26.3	14.6	59.1
107	13.07	11.16	28.35	163.3	69.7	394.0	26.1	11.1	62.8
108	13.15	23.77	21.24	164.4	148.5	295.0	27.1	24.4	48.5
109	6.01	34.13	17.33	75.2	213.5	240.7	14.2	40.3	45.5
110	16.37	30.36	25.46	204.5	189.7	354.0	27.35	25.35	47.3
111	18.62	26.30	29.78	235.2	164.4	413.5	28.9	20.2	50.9

the proportion of TiO_2 and the ratio Fe_2O_3 : FeO. For ores, on the contrary, the mineralogy is much more simple; it is reduced to two or three dominant minerals such as magnetite (and titanomagnetite), ilmenite and hematite (often in segregations). Under these conditions, one realizes that the mixture of definite chemical compounds, $FeO \cdot TiO_2$ and $FeO \cdot Fe_2O_3$, rules in first approximation the ratio between the three oxides TiO_2, Fe_2O_3, and FeO. The position of point No. 96, corresponding to the analysis of the opaque mineral rich rock is significant; as it may be expected, the point lies between the two groups analyses: the rocks on one side, the ores on the other.

The essential conclusion to be drawn from the diagram is in perfect concordance with the deductions based on petrographic and field studies—rocks and ores are genetically related.

Ore Evolution After the Binary Diagram: $FeO \cdot TiO_2$ – $FeO \cdot Fe_2O_3$.—In a detailed work of the ternary system FeO, Fe_2O_3, TiO_2, published in 1926, Professor Ramdohr presented a binary diagram of the relations between magnetite and ilmenite (47). These compounds are insoluble in one another and their behavior is represented by a classical diagram of a binary system with a eutectic (intersection of both liquidus curves), two solidus curves and two "lacunes de solubilité" in the solid states (Fig. 4 a). This figure is incomplete and the interpretation of the sketch is subject to criticism. This will not be discussed here. In this paper I intend only to bring a contribution to the likely position of the eutectic, thanks to the chemical analyses available.

From Figure 4a it is derived that liquids that become richer and richer in TiO_2 as the temperature drops, arise from a magma with a low TiO_2 content. This condition is necessary to maintain equilibrium between the liquid and solid phases. The solid phase is represented by a titanomagnetite (magnetite containing low TiO_2 in the solid state). The occurrence of ores richer and richer in TiO_2 would be accounted for by the crystallization of liquids at lower and lower temperatures. These melts can of course be injected by filter-pressing and be removed from their original medium. This case assumes that the system is open. It follows that the liquid phase may change and reach the eutectic composition because of the progressive separation of the solid and

liquid phases. One can also deduce that the direction of evolution of ores during the differentiation may be fixed. The TiO_2 percentage, and consequently ilmenite, increases regularly when the original magma is poor in TiO_2.

The conclusions to be drawn from the two sets of chemical analyses for the two series of Adirondack titaniferous ores are in full agreement and thus highly valuable.

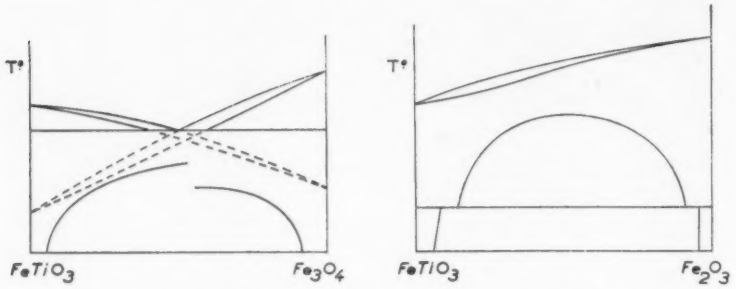

FIG. 4. 4a (left), Ilmenite-magnetite binary system. 4b (right), Ilmenite-hematite binary system. (After Ramdohr (47).)

A different drawing was used (Fig. 3) for each type studied. The first set, Split Rock Mine ore type, was discussed in the preceding section. The second set, Sanford Lake type associated with the ancient saturated intrusion, needs further explanation. All the analyses (Nos. 66 and 112 to 124) fall into the straight line that joins the compounds defined as magnetite and ilmenite. This is by no means surprising as the analyses of this set, published by Kemp (32), indicate only the total Fe percentage. I was bound to introduce the usual hypothesis of the division of Fe between Fe^{++} and Fe^{+++} in order to form at first $FeO \cdot TiO_2$, then with the rest, $FeO \cdot Fe_2O_3$. The oxide distribution was made, accordingly, for each analysis, the approximate composition of the mixture $FeO \cdot TiO_2 + FeO \cdot Fe_2O_3$. It is remarkable that in both sets (ores from saturated and undersaturated series) ilmenite does not exceed 60 percent. The sole point, No. 124, that falls in the environment of the theoretical composition of ilmenite (less than 2 percent Fe_2O_3) only emphasizes the blank between the ilmenite and the other representative points of the ore. Such close connections in the composition of ores coming from the same region are not mere chance (22 analyses); they confirm the idea of an equilibrium, during the cooling, in the magmatic masses. They impose, for these deposits, the principle of a differentiation process. One must not forget that these analyses concern ore series, and each entire series was derived from only one magma.

The initial composition of each magma will thus be the starting point for each differentiated series. At the beginning, the TiO_2 percentage was low, as shown by the anorthosite and gabbro analyses. Consequently, it is reasonable to conclude, from these statistical measures, that the upper limit in TiO_2 relative molecular percentage of ores really corresponds, in the binary diagram for

ilmenite-magnetite, to the eutectic proportions towards which the liquid composition tends to become at the lowest equilibrium temperature. The curve for the Adirondack ores indicates this progression towards a maximum slightly below 30 molecular percent of TiO_2 (slightly less than 57 percent ilmenite).

The conclusion as to the eutectic position, as hereabove defined, does not agree with some observations made by I. Malyshev on the Kusa titaniferous ore deposits (37, 38). According to this author, this ore body was derived from a residual melt of a gabbroic magma injected by filter-pressing in shear zones of cooling rocks. The author also states that the ore structure is fine-grained (0.2 to 0.3 mm). The crystallization sequence depends on the TiO_2 percentage. If there is less than 20 percent ilmenite, magnetite crystallizes first. If there is between 20 and 30 percent ilmenite, the rest being magnetite, the crystallization is simultaneous. On the contrary, ilmenite crystallizes first if its percentage is above 35 percent. The eutectic would be between 20 and 30 percent ilmenite.

There may be some influence of pressure on the position of the eutectic point; however, in general, it is small. One reason for the disagreement between Malyshev's conclusions and mine ought to be investigated, for instance, by the presence of oxides such as Al_2O_3, Cr_2O_3, MgO, and MnO, that commonly are constituents in ilmenite and titanomagnetite and can intensely modify their properties (16, 30).

Generality of the Eutectic.—I desire to discuss a last question. Does the eutectic ratio, derived from a study of the Adirondack rocks, apply in other regions where titaniferous ores are known?

In answer to this question I shall quote a few examples taken from the geological literature, and plot these points on a second ternary diagram (Fig. 5). The data have been divided into two groups:

1. The analyses of ores (I).

2. The analyses of rock opaque minerals (II).

The ore analyses in turn have been distributed into two categories:

I. A. Ores with a grained-texture which after crushing divide into two portions, one magnetic (titanomagnetite and magnetite), the other non-magnetic (ilmenite). In these cases the analyses are given separately for the ore and for each of its constituents.

I. B. The ores analyzed as a whole.

I have applied the same classification for opaque minerals in rocks, and divided them into the following categories:

II. A. Individual analyses of different opaque minerals contained in a rock.

II. B. Analyses of all of the opaque minerals.

II. C. Analyses of rocks that contain the minerals of the preceding categories.

In category I. A. are analyses of:

1. Kakanga ores (Mozambique) described by M. Legraye (Nos. 19, 20, 21).

2. Haaland ores (Norway) (Nos. 1, 2, 3) of which I have observed the same relations as those derived from M. Legraye's inquiries on the preceding ores (Nos. 19, 20, 21).

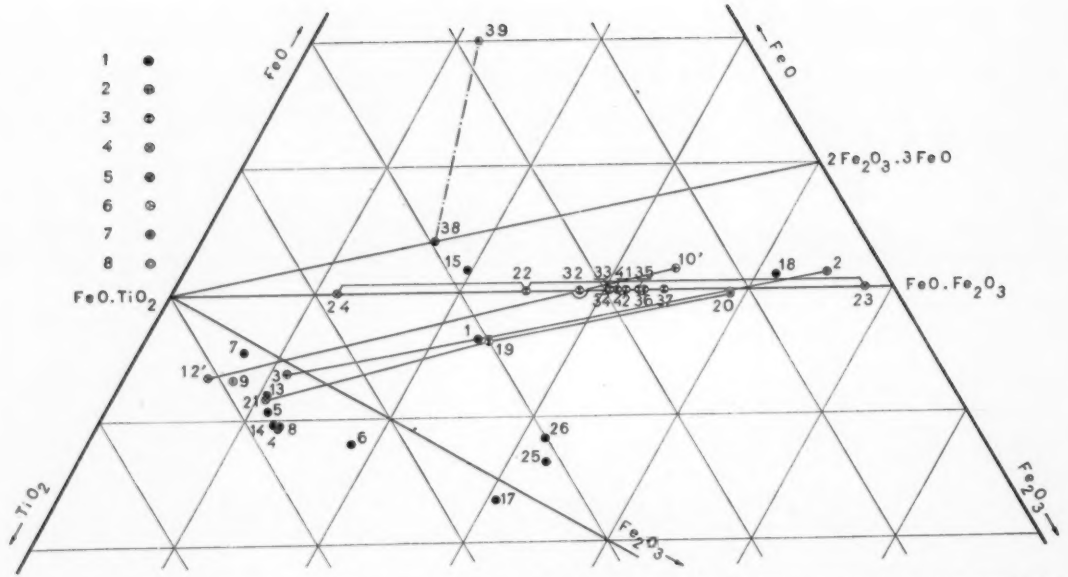

FIG. 5. Explanation: 1. Ore analyses (Nos. 1, 4, 5, 6, 7, 8, 13, 14, 15, 17, 18, 25, 26). 2. Analyses of minerals that are part of one and the same ore (Nos. 2, 3). 3. Analyses of ores for which computation was necessary owing to incomplete data (Nos. 19, 22, 32, 33, 34, 35, 36, 37, 41, 42). 4. Analyses of minerals associated in ores of category 3 hereabove (Nos. 20, 21, 23, 24). 5. Total analysis of opaque minerals contained in a rock (No. 38). 6. Individual analyses of black minerals contained in a rock (Nos. 10', 12'). 7. Total analysis of the rock which contains the minerals quoted hereabove 5 (No. 39). 8. Analysis of the exceptional homogeneous ilmenite from Miask—without any Fe_2O_3 segregations (No. 9). *N.B.* A straight line joins the representative point of an ore to those of the minerals that form this ore.

3. McCuiston ores (Guilford County, N. C.) (Nos. 22, 23, 24), the results of which have been published by W. S. Bayley; unfortunately only the total Fe percentage has been indicated so I had to apply the hypothesis of Fe distribution as FeO and Fe_2O_3 to constitute on one hand $FeO \cdot TiO_2$, on the other hand $FeO \cdot Fe_2O_3$. This explains the position of point No. 24, outside the common limits.

The following analyses are classified in category I. B.:

1. Analysis No. 15 of a coarse-grained ilmenite ore from vicinity of Saguenay River, Bourget County, Chicoutimi District, Quebec, Canada. The ore is made of two different parts (ilmenite and magnetite) but the data given do not allow the computation of each constituent's coordinates.

2. Analysis No. 32 of a titanomagnetite associated with anorthosic rocks. These data have been published by Junner in a study on the Sierra Leone norite (31). The total Fe is indicated as Fe_2O_3. I have computed $FeO \cdot TiO_2$ and $FeO \cdot Fe_2O_3$. Unfortunately there is no description of the ore and no analysis of its constituents.

3. A set of analyses Nos. 33 to 37, published by M. Legraye of Mawili ores (Mozambique), with an intricate texture corresponding to lightly twisted magnetite, titanomagnetite and ilmenite (35).

4. Characteristic ilmenite analyses (Nos. 4 to 9, 14, 21).

5. Analyses of various ores (see index).

In category II. A. I have placed:

1. A titanomagnetite (No. 10') and an ilmenite (No. 12') from a kimberlite pipe (Zefu, Belgian Congo) (58). As these minerals contain a high MgO content, it was necessary to combine this oxide with FeO. I was not able to plot the average point because the proportion of opaque constituents is not given.

In category II. B. is:

1. The analysis No. 38 of opaque minerals of an olivinite from Süsimäki (Finland). The author, K. Palmunen (45), considers that the substance is an association of ilmenite $FeO \cdot TiO_2$ and magnetite with an exceptional composition: $3FeO \cdot 2Fe_2O_3$.

I have placed in category II. C.:

1. An olivinite analysis, No. 39.

On the ternary diagram Fig. 5, I have then joined by a straight line the representative point of an ore with those that define its constituents. For the clearness of the diagram I have not repeated ore analyses of Fig. 3. However the connection will easily be established.

What are the conclusions to be drawn from the examination of Fig. 5 that synthesizes the results of about 40 various analyses?

At first, one may note, as in Fig. 3, that no ore has an average composition lying between ilmenite and a mixture with 60 percent ilmenite.

There is only one abnormal point, No. 24. It is an ilmenite and the reason for this has been pointed out; the point represents an assumed computed composition in which an hypothesis is involved.

The diagram yields one more conclusion. The total chemical compositions that approach the upper limit of 30 molecular percent of TiO_2 involve not only

one but two distinct associated minerals—one a titanomagnetite, the other, an ilmenite. This conclusion is true for ores (Nos. 1, 19, 22, 15) as well as for opaque elements included in an eruptive rock (No. 38).

The coexistence of these minerals—ilmenite and titanomagnetite—is easily understood since they are, in all proportions, insoluble in one another at low temperature. Titanomagnetite compositions in their evolution trend closely along the trace of a magnetite-ilmenite binary system (points Nos. 2, 10′, 20). The compositions of the ilmenite, that represent the other part of the coarse-grained ore, do not follow the trace of the binary system but that of a hematite-ilmenite binary system.

Analyses Nos. 3, 12′ and 21 lie with other minerals and ores that correspond to ilmenites with more or less hematite segregations. The reason for their behavior will be found in equilibrium relations between ilmenite and hematite (Fig. 4b). At high temperatures these compounds are soluble in all proportions but at low temperatures, in the solid states, they show a lack of mutual solubility. Their features have been observed by Ramdohr in many specimens. My own observations agree with the above, which enables one to understand the gap that appears in both diagrams, Figures 3 and 5.

It is also interesting to note that ores as well as opaque minerals contained in rocks tend towards a characteristic individualization and form juxtaposed ilmenite and titanomagnetite grains, provided the molecular TiO_2 amount reaches 30 percent. On the other hand, the ores with lower TiO_2 percentage, such as those that are represented by points Nos. 33 to 37 and 41, 42, show interweaving patterns of their constituents ilmenite, magnetite and titanomagnetite. An explanation could be found for these texture differences in the conditions that determined the formation of these two ore types.

I venture to set forth the following hypotheses: The differentiation processes studied in this paper show that magmas, originally poor in TiO_2, produce during the cooling an uninterrupted series of ores richer and richer in TiO_2. The first solidification stages would give rise to ores with low or medium TiO_2 content and intricate textures. From the schematic binary diagram of magnetite-ilmenite, one may infer that this ore type should crystallize at higher temperature than the grained ores of the second type. Indeed, the composition of the last ones is closer to that of the eutectic. The ores of this type would be related to more advanced differentiation stages. They would have been deposited later, and at lower temperatures. On the other hand, in the course of the cooling of the solid phases the crossing of the solubility curves and unmixing in the solid state would occur for the grained ores at a higher temperature than that which prevailed during the same transformation in the case of the ores lower in TiO_2. Consequently, for the ores of eutectic composition, the transformation temperature would be high enough to allow the coalescence of each of the two principal minerals ilmenite and magnetite; so that a grained texture would appear. In the other case, too low a temperature would reduce the mobility of the elements; the minerals would remain each enclosed in the other. This would result in an intricate texture.

Owing to the lack of data and the impossibility of carrying on personal field observations directed towards my own purpose, I am unable to define

precisely the influence on the ore textures, of the controlling conditions of temperature and pressure. The different types of deposit, either concordant sheets or non-concordant ore bodies, are related to particular temperature and pressure conditions of the surrounding medium. The ore textures should bear the marks of the mode of evolution of the ore.

It is desirable now to compare the theoretical conclusions with field observations.

CONCLUSIONS.

The hypotheses offered here call for some remarks. Unfortunately, I do not possess detailed mineragraphic descriptions for all the minerals and ores analyzed. Syntheses are proposed based on statistical correspondence and by analogy with some well-known occurrences. I have investigated only one ore series ranging from low TiO_2 ores to those in which the TiO_2 molecular proportion reached about 30 percent with regard to the sum of the three oxides TiO_2, Fe_2O_3 and FeO. One half of the diagram is clearly defined. It is related to the crystallization that begins with titanomagnetites and goes toward titanomagnetite associations. There remains the problem of how ores can occur that consist almost wholly of ilmenite; either they are derived from a eutectic ore type by complete separation of ilmenite and titanomagnetite, or, owing to special TiO_2 concentration, the ilmenite represents the first constituent to crystallize.

The second differentiated group, characterized by equilibria between ilmenite and hematite, must be investigated in the same way. A good synthesis would then be possible.

To complete, one should also study the exceptional occurrences such as: homogeneous ilmenite of Miask (without any visible hematite segregation) (analysis No. 9) (61), titanomagnetite rich in MgO, MnO, Cr_2O_3, V_2O_5, etc.; or the opaque minerals of the pegmatites.

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February 12, 1949.

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34. Perthitic association of ilmenite, titanomagnetite and magnetite.
35. See M. Legraye (35), analyses No. 2, 4, 5, 1, 3
36. and P. Evrard (20).
37.

38. Magnetite and ilmenite, Susimäki, Finland; opaque minerals associated in olivinite. Analyst: M. K. Palmunen (45).
39. Olivinite, Susimäki, Finland. Rock which contained the opaque elements of analysis No. 38. Analyst: M. K. Palmunen (45).

41. Titaniferous ore, Liganga, North of Nyassa Lake, Nyassaland.
42. No mineralogical description. Quoted by Stockley (56).

57. [B.–17] * Analysis of composite grab sample of 60 fragments of Marcy anorthosite from 10 localities in core of St. Regis-Marcy unit, along road from Algonquin (Saranac quadrangle) to ½ mile NW from Rustic Lodge (Long Lake quadrangle). Analyst: R. B. Ellestad.
58. [B.–17] Analysis of composite grab sample of about 40 samples of Marcy anorthosite across 2 mile section of Jay sheet, from 1 mile NE of Jay to 0.7 mile W of North Jay (Ausable quad.). Analyst: R. W. Perlich.
59. [B.–18] Composite grab sample of 10 specimens of Whiteface gabbroic anorthosite facies from 5 miles along the strike of northeast border of anorthosite between Lake Flower and North of McCauley Pond (Saranac quadrangle). Analyst: R. B. Ellestad.
60. [B.–19] Composite grab sample of fragments of Whiteface facies of gabbroic anorthosite from 75 localities in area NE of Reber, between it and the belt of Grenville passing

* In brackets is the number of analyses in Buddington's Memoir.

through Sugarloaf Mountain, Willsboro quadrangle. The percentage of mafic minerals was variable. No relics of Grenville or evidences of assimilation were observed. Analyst: R. B. Ellestad.

61. [B.–20.] Analysis of composite grab sample of about 55 fragments of Whiteface facies from section 2½ miles across strike SE from Long Pond outlet to 1½ mile NW of Willsboro (Willsboro quadrangle), and N of the highway. Analyst: R. B. Ellestad.
62. [B.–24] Norite sharply defined band in anorthosite of border facies, 1⁷⁄₁₀ mile W of Gabriels (Saranac quadrangle). Analyst: R. W. Perlich.
66. [B.–28–L.] Ilmenite-magnetite ore. Millpond ore body, near Lake Sanford (Santanoni quadrangle). Analyst: Rossi. Quoted by Kemp (32), p. 388. Osborne (44), p. 740, classifies this as a discordant ore body in anorthosite.
79. [B.–50] Metagabbro ⅖ mile SE of Geers Corners and about 750 ft. S of No. 80 [B.–51] (Lake Bonaparte quadrangle). Analyst: R. B. Ellestad.
80. [B.–51] Metagabbro ¼ of a mile E of Geers Corners, about 100 ft. S of the contact with limestone. Analyst: R. B. Ellestad.
81. [B.–52] Metagabbro, 1⅛ mile NNW of Laidlaw School (Hammond quadrangle), upper part of Pleasant Lake sheet. Analyst: R. B. Ellestad.
82. [B.–55] Garnet-hornblende amphibolite, 2½ miles ESE of St. Regis Falls (Nicholville quadrangle). Analyst: A. Willman.
83. [B.–56] Metagabbro, 7⁄₁₀ of a mile NNW of School No. 7 (Santa Clara quadrangle). Analyst: A. Willman.
84. [B.–57] Metagabbro (amphibolite); 1½ mile south of Brandon (Malone quadrangle). Analyst: A. Willman.
85. [B.–58] Metagabbro ⅓ of a mile of Henry School, 1⅗ mile NE of Croghan (Lowville quadrangle). Analyst: R. B. Ellestad.
86. [B.–59] 1⁹⁄₁₀ mile WSW of Jerden Falls and 3 miles S of Caroll School (Lake Bonaparte quadrangle). Analyst: A. H. Phillips.
87. [B.–60–L.] Massive gabbro 2 miles S of Elizabethtown. Quoted by Kemp and Ruedemann (33); p. 55. Analyst: W. F. Hillebrand.
88. [B.–61–L.] Gneissoid gabbro, same locality as 87. Quoted by Kemp and Ruedemann: (33), p. 55. Analyst: W. F. Hillebrand.
89. [B.–62] Metagabbro, fine-grained granoblastic aggregate at contact of metagabbro with anorthosite. N border of Port Henry quadrangle on road along W side of Split Rock Mountain. Analyst: R. B. Ellestad.
90. [B.–63–L.] Metagabbro, wall-rock of titaniferous magnetite, Split Rock Mine, West Port (Port Henry quadrangle). Quoted by Kemp (32), p. 399–400. Analyst: W. F. Hillebrand.
91. [B.–64–L.] Woolen Mill gabbro, 1 mile W from Elizabethtown. Quoted by Kemp and Ruedemann (33), p. 55. Analyst: W. F. Hillebrand.
92. [B.–65–L.] Metagabbro, 1¼ mile S of "The Glen" (North Creek quadrangle). Quoted by Miller (41), p. 32. Analyst: E. W. Morley.
93. [B.–66] Pyroxene-garnet-olivine-andesine metagabbro. Core of dyke extreme NE end of Trembleau Mountain, ⅔ mile of Trembleau Point (Plattsburg quadrangle). This specimen is typical of much of the metagabbro within the anorthosite. Analyst: R. B. Ellestad.
94. [B.–67] Pyroxene-garnet-andesine granulite. Border facies of same metagabbro dyke as 93. Analyst: R. B. Ellestad.
95. [B.–68–L.] Wall-rock of titaniferous magnetite. Lincoln Pond (Elizabethtown quadrangle). Quoted by Kemp (32), p. 406–407. Analyst: George Steiger.
96. [B.–69] Mafic metagabbro band in gabbro, ⅔ mile E of McCauley Pond (Saranac quadrangle), ½ mile N of railroad. Analyst: A. Willman.
97. [B.–70L.] Ross ore bed, Oak Hill, about 1 mile N of New Russia. Quoted by Kemp and Ruedemann (33), p. 136. Analyst: W. F. Hillebrand.
98. [B.–71–L.] Ore Split Rock Mine (Port Henry quadrangle). Quoted by Kemp and Ruedemann (33), p. 136.
99. [B.–72–L.] Ore, Tunnel Mountain Mine, 3½ miles S Elizabethtown. Quoted by Kemp and Ruedemann (33). The ore consists of magnetite, ilmenite, brown hornblende, olivine, garnet and plagioclase.
100. [B.–73–L.] Ore, Lincoln Pond. Quoted by Kemp and Ruedemann (33), p. 145. Analyst: W. F. Hillebrand.
105. Titaniferous ore of the Adirondacks (Split Rock-Westport). Kemp (32), analysis No. 11. The wall-rock of this ore is analyzed at No. 90. Analyst: Maynard.
106. Titaniferous ore of the Adirondacks (Tunnel Mountain, Elizabethtown). Kemp (32), analysis No. 1. Analyst: W. F. Hillebrand.

107. Titaniferous ore of the Adirondacks (Little Pond, Elizabethtown, South Pit). Kemp (32), analysis No. 2. Analyst: W. F. Hillebrand.
108. Titaniferous ore of the Adirondacks (Kingdom Mines, Elizabethtown). Kemp (32), analysis No. 4. Analyst: Maynard.
109. Titaniferous ore of the Adirondacks (Norway Mine, Westport). Kemp (32), analysis No. 4. Analyst: Maynard.
110. Titaniferous ore of the Adirondacks (Iron Mountain, Elizabethtown). Kemp (32), analysis No. 8. Analyst: Maynard.
111. Titaniferous ore of the Adirondacks (Little Pond, Elizabethtown, North Pit). Kemp (32), analysis No. 9. Analyst: W. F. Hillebrand.
112 to 124. Analyses of ores near Sanford Lake (Newcomb Township, Adirondacks). Kemp (32). The analyses No. 66 and Nos. 112, 113, 114, 115 are of ores from Millpond Pit; Nos. 116 and 117 are from Cheney Pit and Nos. 118 to 124 from Sanford.

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DISCUSSION AND COMMUNICATIONS

MINERAL RELATIONSHIPS IN THE ORES OF PACHUCA AND REAL DEL MONTE, HIDALGO, MEXICO.

Sir: To one whose professional work for the last ten years has been devoted almost continuously to geologic study and exploration in the Pachuca-Real del Monte district, Hidalgo, Mexico, the recent discussions between two such able geologists as Professors Edson S. Bastin [1, 2] and Edward Wisser [3] hold a great deal of interest.

Professor Bastin mentions in his discussion that in the Pachuca-Real del Monte district, mining on an important scale has ceased with the recent withdrawal of the United States Smelting Refining and Mining Company. The Real del Monte Company, now owned by Mexican-government-controlled agencies, has not, however, reduced its mining operations. Several of the old mines are now being re-opened; exploration is still vigorously carried on, and the monthly tonnage is practically the same as that extracted during the last few years. I might add that at present the number and extent of accessible levels are about the same as in previous years.

The present policy of the company is to prolong the life of its mines as much as possible. Eventually, its operations in this district may be reduced, in a gradual way, to a more modest scale. Like human beings, operations in mining districts have in their very birth the implications of a final death, and this district is, of course, no exception.

In Figure 1 (p. 282) of Professor Wisser's Reply referred to above, he shows a rather constant decrease of lead-zinc ratios in the North-South veins in Real del Monte, from north to south. Since blende is considered one of the early minerals to be deposited, and galena one of the later ones, he concludes ". . . the mineralogy described suggests growth of North-South Real del Monte vein fractures, in general from north to south" (p. 285).

During the past few years there have been rather extensive drifting and stoping in the North-South Real del Monte veins, especially between the San Esteban fault and the Gran Compaña vein; those vein stretches that show prominent lead-zinc sulphides are now being stoped, and this ore is treated at the company's small flotation plant that was recently erected. Consequently, present data regarding lead-zinc sulphides in the district are now more complete and representative than were those to Professor Wisser. Recently com-

[1] Bastin, Edson S., Mineral relationships in the ores of Pachuca and Real del Monte, Hidalgo, Mexico: ECON. GEOL., vol. 43, No. 1, pp. 53–65, January–February, 1948.

[2] Bastin, Edson S., Discussion of paper by Edward Wisser, Mineral relationships in the ores of Pachuca and Real del Monte, Hidalgo, Mexico—a reply: ECON. GEOL., vol. 43, No. 6, p. 525, September–October, 1948.

[3] Wisser, Edward, Mineral relationships in the ores of Pachuca and Real del Monte, Hidalgo, Mexico—a reply: ECON. GEOL., vol. 43, No. 4, pp. 280–292, June–July, 1948.

puted ratios, given below, for the same veins as those used by him, show that there is not a constant decrease in lead-zinc ratios from north to south.

For the benefit of persons not acquainted with Pachuca, it may be remarked parenthetically that the averages of total PbS-ZnS do not represent averages for the entire lengths of N-S veins comprised by the brackets, as shown by Professor Wisser in the same Figure 1. They refer only to those stretches along the veins where these sulphides are more abundant. The same condition applies to the table showing the present averages. It should be emphasized that the base-metal sulphide production has never played a major economic role in the district. For many years the mill heads averaged hardly more than traces of these metals.

Wisser's averages			Present averages	
Av. Pb-Zn ratio	Av. total PbS-ZnS	North-south veins	Av. Pb-Zn ratio	Av. total PbS-ZnS
1:4.8	12.8	Between Ompaquez and San Esteban	1:4.1	12.0
1:4.2	11.2	Between San Esteban and Gran Compaña	1:1.9	11.1
1:3.1	6.7	Between Gran Compaña and Vizcaína	1:3.2	6.7
1:2.4	8.7	South of Vizcaína	1:2.0	8.4

N ↑ S

Since Professor Wisser's departure from Pachuca in the latter part of 1936, some 240 kilometers of exploration and development work, and some 95 kilometers of diamond drilling have been done in the district. The geologic information gathered as a result of this extensive work has been considerable, and in many instances has modified earlier concepts, especially those regarding structural geology; several new ore bodies have been discovered, one of these illustrating a type of precious-metal ore not included in previous descriptions. A review, now under way, of the field relations of the ore bodies and structures will, it is hoped, bring more up to date the published data regarding these features of the district.

A. R. GEYNE.

PACHUCA, HIDALGO, MEXICO,
January 24, 1949.

ORE AND GRANITIZATION.

Sir: Mr. Sullivan's thesis [1] that deposits of chalcophile and siderophile elements in the crust have increased, both relatively to lithophile elements, and absolutely, in younger metallogenetic provinces as a result of addition of material from the deeper zones of the earth, is stimulating to the imagination, in that it offers a new concept to replace, or at least modify, the views expressed by Niggli and others as to the relation between types of mineral deposit and the degree of erosion that has affected a metallogenetic province. Exception must be taken, however, to his uncritical selection of data. A number of his statements involve misconceptions, and some of his "facts" are of questionable validity.

[1] C. J. Sullivan, Ore and granitization: ECON. GEOL., Vol. 43, pp. 471–498, 1948.

On p. 475, under the heading *Lithophile Elements,* he implies that thorium deposits are restricted, as regards their origin, to Precambrian and Paleozoic granites. This is to overlook the occurrence of considerable quantities of monazite in the Mesozoic granites of Malaya and the "tin islands" of the Netherlands East Indies. In 1936, production of monazite from the N.E.I. was 668 metric tons, as compared with no production from Brazil, and 2670 metric tons from Travancore; in 1938, it was 393 tons from the N.E.I., 323 tons from Brazil, and 5305 tons from Travancore.[2] The presence of monazite associated with detrital cassiterite in Malaya is well attested. Scrivenor[3] states that "monazite is of common occurrence with cassiterite in detrital deposits (in Malaya) and has been found in a granitic rock near Lenggong in Upper Perak." He intimates that the monazite is readily concentrated in considerable tonnages, but has a low thorium content, which militates against its marketing in competition with monazite from other sources. Clearly, production is not a true measure of the relative amounts of thorium in these various regions, but is a reflection of the market for monazite and for the allied minerals being produced in these several regions, of whose production it is a by-product.

Also on p. 475, Mr. Sullivan states that tantalum and niobium (columbium) are "produced mainly from pegmatites of ancient terrains," and that "later granites have not concentrated important quantities of these elements"; and on p. 476, he notes a "contrast in time distribution between the siderophile element tin, and the related, but lithophile elements tantalum and columbium (niobium)." Is this correct? In Nigeria, tantalum, columbium and tin are associated together both in the older pegmatites and the younger granites of that region. The younger granites, in which the association is chiefly columbium with tin, intrude Precambrian rocks, and are overlain by Upper Cretaceous sediments. Their age is uncertain; they may be Precambrian, but the possibility that they are Cretaceous has been mooted.

Tin, tantalum and columbium occur together in the Belgian Congo, and in the Black Hills, South Dakota. At Greenbushes, in Western Australia, tin and tantalum (plus columbium) are intimately associated, and they also occur together at Strelley, Pilgangoora and Moolyella in that state.

Tantalum is also associated with tin (derived from Mesozoic granites) in Malaya,[4] occurring as free minerals, and also intergrown with, or in solid solution in, cassiterite, as at Greenbushes. On occasion, the amount of tantalum present is sufficient to be troublesome in the preparation of clean cassiterite concentrates.

In view of the great quantity of cassiterite mined in southeastern Asia, there is a possibility that the *total quantity* of tantalum (and columbium)

[2] Figures from Mineral Industry for 1940, Vol. 49.

[3] J. B. Scrivenor, Geology of Malayan Ore Deposits, p. 143, Macmillan, New York, 1928.

[4] C. J. Sullivan, Tantalum and columbium: Mineral Resources of Australia, Summary Rept. No. 19, 1945; Min. Res. Survey, Dept. of Supply and Shipping, Australia.

On p. 7, Mr. Sullivan writes—"tantalum and columbium minerals together with a number of other complex heavy minerals were obtained as a by-product concentrate from Malayan tin-dredging. The complex nature of the concentrates hindered economic extraction of the tantalum-columbium content."

associated with the Mesozoic granites there is quite as great as that occurring in slightly more concentrated form in some of the producing areas.[5]

In connection with tin, Mr. Sullivan states on p. 476 that "tin is normally associated with acid granite, and that Daly (Igneous Rocks and the Depths of the Earth) has estimated that nine-tenths of the acid granites occur in the Precambrian," but despite this "the early Precambrian terrains are conspicuously poor in tin, despite their high proportion of acid granites." This is a misconstruction of the facts. The "tin-granites" are conspicuously silica-rich, even among "acid" granites, and are abnormally low in Mg and Ca. The average Precambrian granite cited by Sullivan (pp. 474, 476) has 71 percent silica, whereas typical "tin-granites" in New South Wales (New England) contain from 74 to 76.5 percent silica, those of Queensland (Stanthorpe) from 76.5 to 77 percent silica, and those of Tasmania (Blue Tier) from 74.5 to 77 percent silica. The "tin-granites" of Saxony, Cornwall and Malaya are comparably rich in silica.

Further, tin deposits associated with such granites are conspicuously concentrated about the summits or margins of cupolas and stocks; and to overlook the possible dispersive effects of erosion in Precambrian areas is to unfairly weight one's argument.

On p. 477, "it is concluded that acid granites will give rise to tin deposits only when tin is available within the sialic material from which the granite is formed"—and somewhat contradictorily, on the same page "that tin may be introduced into the crust by volcanic rocks," which include rhyolites. This involves the implication—not proved—that "tin-granites" are a product of granitization. It may be noted in this connection that in the New England district of New South Wales, and in the contiguous Stanthorpe district of Queensland, and again in the Blue Tier district of Tasmania, the "tin-granite" has intruded an earlier barren granite (granodiorite or adamellite), which on Sullivan's line of argument, might be expected to be "the sialic material from which the (tin-bearing) granite is formed."

The statement on p. 475 that "the lithophile elements are not found associated with 'volcanic' activity; the addition of basic magma to the crust merely dilutes the concentrations of these elements," appears to overlook the predominance of *lithophile* elements, viz., Si, Ti, Mg, Al, Ca, Na, K, P, and Mn in basic magmas, as represented by basalt or eclogite.

Need for a Collector Mechanism.—The only "collector" mechanism suggested in the paper is one of "rejection" of the atoms of siderophile and chalcophile elements from the crystal structures of quartz and feldspar. Thus, on p. 485—"these types (B, F) are commonly concentrated along with tin and the other elements enumerated (W, Ta, Nb, Bi, Mo), the reason being that they are not readily accepted into the lattices of the common rock-forming minerals."

[5] Total production to the end of 1944 from Wodgina, Western Australia, was 223 tons of 65% Ta_2O_5, and for Western Australia as a whole was 282 tons of 65% Ta_2O_5.

Tin production in S. E. Asia for 1940 was: Malaya 85,384 long tons, N.E.I. 44,447 tons, Siam 17,447 tons, a total of 142,278 long tons. Assuming this to average 0.001% Ta_2O_5, the tonnage of Ta_2O_5 involved would be about 1.4 tons.

Is it not more likely that strongly polarizing cations like Sn^{4+} and W^{4+} would link with highly polarized halide ions, to form strongly bonded molecules in which the anions would be so distorted that the bonding would become homopolar, rather than ionic in character? Such molecules, with strong internal coherence, and little excess or external bonding force, would tend to remain as isolated units—that is, as a highly stable gas phase at the prevailing temperatures. In a *magma,* they could be pictured as floating up into the upper crystallizing mass, where so long as the cation had its insulating sheath of halide ions, they would accumulate, and condense. Subsequent hydrolysis at relatively low temperatures would be inevitable.

In seeking an explanation of the concentration of certain elements, as nickel, Mr. Sullivan offers suggestions that are in conflict with the whole argument regarding isomorphous substitution of elements of similar ionic radius and ionic charge which he has previously invoked (p. 484). Thus, on p. 487, he suggests that nickel may substitute for magnesium more readily in diopside $CaMgSi_2O_6$ than in hypersthene $(FeMg)_2Si_2O_6$, so that in the norites the nickel "is available for emplacement in ore deposits." In view of the similar ionic radii and charge of the ions Ni^{2+} 0.74, Mg^{2+} 0.75, the Ni-content of Mg-minerals should be governed solely by the relative proportions of Ni and Mg in the melt from which the minerals crystallize, and should remain constant for all Mg-minerals formed from that melt. A similar substitution of Ni^{2+} for Fe^{2+} 0.83, would be expected, but substitution for Ca^{2+} 1.01 would be less easily effected, so that hypersthenes should normally carry more Ni than diopside crystallized from the same melt. To expect unmixing of nickel from hypersthene is to misconceive the principles involved. It is useless to invoke the possibility of lattice defects as an aid to diffusion, because it would be Mg^{2+} that would diffuse out of the hypersthene and not Ni^{2+}.

The argument (p. 486) that "gold is preferentially concentrated by the soda-rich albite porphyries, possibly for the reason that gold may substitute for potassium" is equally difficult to concede as a reason for the concentration of gold in or near albite porphyries. It is, however, a fair argument for the purpose of keeping gold *out* of the albite-porphyries. The spatial concentration of the gold is left unexplained. There would be no tendency for the unwanted Au^{+} ions to collect ahead of or in the margins of the albite porphyry bodies unless it is assumed that the Au ions are combined with anions (Cl, F ?) to give more volatile material immiscible with albite porphyry melt (or ichor).

The references on p. 484 to "the *anions* Na^{+}, K^{+}, Ca^{2+}, and Al^{3+}," and to silicon as "a very small *anion* with a high charge" are presumably slips or printers errors.

Ore and Granitization.—Some of Sullivan's arguments in support of his granitization contention involve serious misconceptions.

On p. 490, and more precisely on p. 495 (4) it is implied that pyrometasomatic (contact metasomatic) ore deposits are related to synchronous batholiths rather than to subsequent batholiths. This is the reverse of the writers'

(limited) experience in Australia, where the pyrometasomatic ore deposits known to him are associated with cupolas or stocks of typical subsequent intrusions, viz.—

(1) Heemskirk, Tasmania—successive zones of (1) tin ore in the granite (2) magnetite skarn with tin or sulphides in the contact aureole (3) pyrite-sphalerite ore (4) pyrite-galena ore (5) galena-silver-carbonate ore in the outermost zone, still with some cassiterite, and with stannite in one or two deposits.

(2) Meredith Range, Tasmania—skarn with tin and sulphides in the contact aureole of the granite. The tin is chiefly as cassiterite.

(3) Moina, Tasmania—skarn with Sn, W, Mo, Bi at a granite-limestone contact, and in adjacent pegmatitic ore, with outer zones of gold-pyrite ores and lead-silver ores.

(4) King Island, Tasmania—a contact aureole, with andalusite hornfels, calc-flinta, and marble beds altered to andradite-skarn carrying scheelite, a little Mo, and traces of sulphides.

(5) Yetholme, New South Wales—molybdenite in a garnet-pyroxene skarn developed from limestone at or near a granite contact.

(6) Glassford Creek, Queensland—copper ores associated with garnet skarn at a granite contact.

(7) Chillagoe district, Queensland—copper and lead-silver ores associated with andradite-skarn formed from limestone close to a granite contact.

The list could be extended to other countries. Thus Lindgren (Mineral Deposits) lists as pyrometasomatic (contact metasomatic) deposits associated with laccoliths and stocks of granodiorite porphyry, granite porphyry and quartz monzonite, the copper deposits of San Pedro (New Mexico), Clifton (Arizona), Bisbee (Arizona), Silver Bell (Arizona), Cananea (Mexico) and Bingham (Utah).

On p. 494, it is stated that the tin ores of the Mount Bischoff-Renison Bell tin field of Tasmania "are obviously related to quartz-porphyry dykes, and it has been assumed that these porphyries are of granitic origin." This may be so, but the reader will look in vain for such a statement in the paper to which Mr. Sullivan makes reference.[6] His further statement that these tin ore deposits "are quite different from those normally related to granite, as the cassiterite is in fine-grained aggregates and is associated with massive sulphides (pyrite and pyrrhotite)." . . . "Massive sulphides are uncommon in tin deposits related to granite batholiths," is not substantiated by the facts. The tin ores of Mount Bischoff and Renison Bell are simply "telescoped ores," in which the early stages of deposition represent normal deposition of cassiterite, topaz, tourmaline, followed by introduction of the sulphide minerals as mineralization progressed. In the Meredith Ranges, a few miles distant, rather similar ore is developed with skarn in the contact aureole of a granitic stock that carries normal cassiterite deposits in its marginal zone;[7] and in the Heemskirk-Zeehan district, some miles to the south-west, the equivalent of the "telescoped" ores of Renison Bell appears as a series of "zoned" deposits as one proceeds outwards from the granite stock of Mount Heemskirk to-

[6] F. L. Stillwell and A. B. Edwards, The mineral composition of the tin ores of Renison Bell, Tasmania: Australasian Inst. Min. Metallurgy Proc., No. 131–132, pp. 173–186, 1943.

[7] L. L. Waterhouse, The Stanley River Tinfield: Tasmania Geol. Survey Bull. No. 15, 1914.

wards Zeehan township.[8] In the granite, and at its margin, are normal cassiterite ores, the more marginal deposits carrying small amounts of sulphides. In the contact zone are bodies rich in magnetite, some of which carry cassiterite in small amounts. Some consist of magnetite and lime silicates (skarn), some of magnetite and sulphides. Others further from the granite carry pyrrhotite, pyrite, chalcopyrite, sphalerite and galena in addition to abundant magnetite.

Further from the granite is a pyritic zone, with sphalerite more abundant than galena in the inner part of it, and the reverse in the outer part. This gives place, near Zeehan, to the outermost zone where galena and silver minerals prevail, commonly with a carbonate gangue. Small veins with cassiterite or cassiterite and pyrite are found here, and some of the galena veins carry a little cassiterite and abundant stannite. The progressive changes in the composition of the mineralization at these various stages in the outward progress from the Heemskirk granite closely resemble the changes in composition that accompanied the progressive deposition in the Renison Bell and Mount Bischoff lodes.

At the north-eastern end of this tin province, cassiterite is again found in and adjacent to a granite stock at Moina, part of the tin occurring in skarn rocks, and part in pegmatite dikes. Outwards from the granite contact the proportion of sulphides associated with the cassiterite increases, and the mineralization changes first to a gold-pyrite-quartz mineralization, and then in an outer zone to a lead-silver mineralization.[9]

"Telescoped" cassiterite-sulphide ores such as those of Mount Bischoff and Renison Bell are not limited to Tasmania. They are found in the Herberton field of Queensland, alongside normal tin ores, *e.g.*, Brass Bottle, Consolation, Lancelot and Isabella ore bodies, to mention only those of which the writers have personal knowledge. Others are listed by Blanchard.[10] One of us has examined a similar ore from South Thailand (Siam), where it was associated with the normal tin ores of S. E. Asia, and there is record of such ores associated with normal cassiterite ores at Klappa Kampit and Garoemedang, on Billiton Island, in the Netherlands East Indies. No "volcanic" influence is required to account for any of these ores. In fact, tin is apparently absent from all parts of the N.E.I. and adjacent islands that are removed from the granitic areas of "Sundaland," despite the abundance of volcanic rocks, and basic intrusives in such areas.[11] The Bolivian cassiterite-sulphide ores also may be of this "telescoped" type, but the writers have no personal knowledge of them. It may be noted, however, that the resemblance of the

[8] W. H. Twelvetrees and L. Keith Ward, The ore bodies of the Zeehan field: Tasmania Geol. Survey Bull. No. 8, 1910. L. Keith Ward, An investigation of the relationship of the ore bodies of the Heemskirk-Comstock-Zeehan region, and their associated igneous rocks: Australasian Assoc. Adv. Sci. Proc., Vol. 13, pp. 153–164, 1911.

[9] W. H. Twelvetrees, The Middlesex and Mount Claude mining field: Tasmania Geol. Survey Bull., No. 14, 1913. A. M. Reid, The mining fields of Moina, Mount Claude and Lorinna: Tasmania Geol. Survey Bull., No. 29, 1919.

[10] R. Blanchard, Some pipe deposits of eastern Australia: ECON. GEOL., Vol. 42, p. 265, 1947.

[11] A. B. Edwards and M. F. Glaessner, The mineral resources of the western Pacific islands: Australasian Inst. Min. Metallurgy Proc. (in press).

Renison Bell-Mount Bischoff ores is to Ahlfeld's "normal" type of deposit associated with the Quimsa Cruz batholith, and to the deposits of Uncia-Llallagua which are associated with quartz-porphyry necks, and are described by him as hypothermal.[12] There is no counterpart of the silver-rich epithermal types of Bolivia.

Significance of Erosion.—On p. 481, the statement is made that "the evidence presented shows that there is but little correlation between the temperature of formation of ore deposits and their distribution in geological time, and hence that Niggli's explanation on the basis of depth of erosion is probably untenable." The logic of this is unsound. It implies that high temperature deposits are formed only at great depths. To the writers it seems that temperature and pressure can be independent variables in ore deposition. The pressure relates to (a) the depth below the surface at which deposition occurs, and (b) the vapor pressure of the ore-bearing emanations. The temperature relates to the height above (or distance from) the intrusion from which the emanations derive, so that high temperature epithermal deposits are both a possibility and a fact. As an example, a close parallel is found in the paragenesis (and hence presumably in the temperatures of deposition) of the gold-telluride ores of Vatukoula, Fiji (epithermal) and of Kalgoorlie, Western Australia (hypothermal according to Lindgren, probably mesothermal).[13]

Sullivan, on p. 476, indicates that similar relations may be found with copper ores. His contention that basic magma is relatively rich in copper, and that copper deposits may be the outcome of progressive enrichment of the crust in this element through admixing of basic magma, may well be conceded, but the argument dismissing the importance of erosion as a factor in the exposure of copper deposits selects only the favorable instances (p. 476). It is interesting to note that in the series of young mountain chains extending from Japan, through the Philippines, Borneo, Celebes, New Guinea, the Solomon Islands, New Caledonia to New Zealand, "basic magma" carrying Cr and Ni is abundantly developed, but with the exception of Japan these regions appear surprisingly deficient in significant deposits of Cu, Zn, Pb, Sn, W or Mo. The Japanese deposits are not large, and many of them are pyrometasomatic (contact metasomatic) deposits, as are the few deposits of these elements found in Sumatra and Celebes. Presumably in the islands other than Japan there has not been, as yet, sufficient erosion to expose more than an occasional deposit of this type.

The abundant tin deposits of S. E. Asia, extending to Singkep, Banca and Billiton, the southeast margin of Sumatra, the southwest corner of Borneo, and the Anambas and Natoena Islands bordering the South China Sea, provide a pronounced contrast, all these deposits being associated with exposed granites within the borders of the old "Sundaland," and cutting out abruptly as soon as the "mobile belt" of the Sunda Islands is encountered. Either erosion has penetrated deeper in "Sundaland" or the granites there came closer to the surface.

[12] F. Ahlfeld, The Bolivian tin belt: Econ. Geol., Vol. 31, p. 48, 1936.

[13] F. L. Stillwell, Occurrence of tellurides at Vatukoula, Fiji: Australasian Inst. Min. Metallurgy Proc. (in press).

The assumption that Niggli's thesis is "probably untenable" overlooks the fact that erosion has proceded to greater depths in Precambrian terranes, generally, than in young mountain chain regions, and the likely significance of this when considered in conjunction with Emmons' observations on the distribution of ore deposits in relation to batholiths.[14] It is conceivable that Niggli's thesis requires to be modified in the light of Mr. Sullivan's suggestion, but in the light of the evidence presented, Mr. Sullivan's alternative concept remains no more than a suggestion. A much more critical and balanced discussion will be necessary to raise it above that status.

A. B. Edwards and A. J. Gaskin

Geology Department,
University of Melbourne,
January 10, 1949.

[14] W. H. Emmons, On the mechanism of the deposition of certain metalliferous lode systems associated with granitic batholiths, Chap. VII *in* Ore Deposits of the Western States, Lindgren Volume, Am. Inst. Min. Met. Eng., 1933.

REVIEWS

Dana's Minerals and How to Study Them. By the late EDWARD SALISBURY DANA, revised by CORNELIUS S. HURLBUT, JR., 3rd Edit. Pp. 323; figs. 386, appendix. John Wiley & Sons, New York, 1949. Price, $3.90.

This book long prized by the amateur has been refurbished again to whet his appetite and increase his knowledge. It starts out with simple definitions, then takes up crystals, physical and chemical properties, and identification. In this edition the minerals are grouped according to chemical classification. Two appendices list the common minerals according to elements, and those important for a small collection. The frontispiece is a lovely colored plate, and many good photographs entice the amateur's interest.

Principles of Petroleum Geology. By CECIL G. LALICKER. Pp. 377; figs. 157. Appleton-Century-Crofts, Inc., New York, 1949. Price, $5.00.

This is a needed textbook on Petroleum Geology. It is surprising that despite the voluminous literature on the geology of petroleum, despite the many books on various specific phases of petroleum geology, only one textbook covering the whole field of petroleum geology has been extant—and at that written by one who was not a petroleum geologist. This book therefore is welcome as a stimulus to the teaching phase of the science.

A preliminary chapter of a few pages touches the development of petroleum theories. Chapter 2 deals with the Geographic and Stratigraphic Distribution of Petroleum and ends with World Petroleum Reserves. Chemical and Physical Properties are given in Chapter 3. The Origin, Migration, Accumulation, Reservoir Rocks, Classification, and Origin of Structures, are covered rather briefly in the next five chapters totaling 68 pages, which seems too small a proportion devoted to principles and processes.

The following chapters include Anticlines, Domes, and Synclines; Reservoirs Caused by Faulting; Salt Dome Oil Fields; Buried Hills; Stratigraphic and Porosity Type Fields; Petroleum Discovery Methods; Geological Considerations in Recovery Methods; Valuation of Oil and Gas Properties. In the chapters relating to structures, an introductory paragraph is followed by descriptions of selective individual fields from different parts of the world illustrative of those structures. Thus, from page 126 to page 289 is entirely descriptive. This is a rather large amount of description to make the book most desirable as a textbook. This arrangement also omits consideration of the outstanding features of larger units or provinces, such as that of the Gulf Coast, or Rocky Mountain provinces. A number of clear line drawings illustrate structures, stratigraphy, and geophysical results; photographs are confined to 6.

The book is well written and should find a place in every petroleum geologist's library.

Historical Geology. By CARL O. DUNBAR. Pp. 567; figs. 350. John Wiley & Sons, New York, 1949. Price, $5.00.

This new-born successor to the widely known predecessors, "Textbook of Geology, Part II, Historical Geology," first by the late Charles Schuchert, and in later editions by Charles Schuchert and C. O. Dunbar, is so much revised as to be almost a new book. This is helped by a large number of new and excellent illustrations, many taken of material in Peabody Museum and of the bleed type reproduced on heavy coated paper.

The objectives of the earlier book have been retained, but in the rewriting emphasis has been varied in the different chapters so as to break the monotony of treatment so common to historical geology treatments. The story is told in the illustrations as well as in the text.

The former organization is largely retained, but one notes changed introductory chapters to bring the time scale and strata sequence at the beginning of the students' introduction to the subject.

This new edition is also supplemented by a set of color slides prepared to illustrate the subject matter. "Historical Geology" is a fitting companion to the fine new "Physical Geology" and together they should continue to command the position of being the leading textbooks for a full year course in elementary geology.

Sedimentary Rocks. By F. J. PETTIJOHN. Pp. 526; figs. 131; pls. 40; tbls. 139. Harper & Brothers, New York, 1949. Price, $7.50.

Carey Croneis, the Editor of the Harper's Geoscience Series, of which this volume is the seventh, says in his introduction: "Our editorial suspicion is that it will become one of the more useful of the many textbooks on various of the fundamental aspects of geology." The fly leaf states that "this distinguished volume . . . is certain to become the classic text . . . concerned with sedimentary rocks. It is probably the most useful single volume guide yet published to the observation, classification, and interpretation of one of the most basic phenomena in geology."

The book takes up the common sedimentary rocks and many new concepts regarding them are presented. Here are the chapter headings: Introduction, Textures, Composition, Structures, Color, Classification, Conglomerates and Breccias, Sandstones, Shales and Argillites, Limestones and Dolomites, Nonclastic Sediments, Weathering, Transportation, Deposition, Lithification and Diagenesis.

The presentation of the subject matter is clear and direct and the book will serve not only as a stimulating elementary text but also as a more advanced reference. The professional geologist will find much use for it. The well-balanced text matter is supported by 139 useful tables, good line drawings, and particularly noteworthy is the careful selection of general photographs and 104 photomicrographs, all excellently reproduced as colotypes. This pleasing feature is unique in textbooks and combined with the unusually fine printing help make this volume stand apart from other petrology textbooks.

Die Bergwirtschaft der Erde, 4th Edit. By FERDINAND FRIEDENSBURG. Pp. 574; figs. 56; numerous tables. Ferdinand Enke Verlag, Stuttgart, 1948. Price, bound, D.M. 58.–

This survey of the mineral wealth, mining, and supply of metals and minerals first appeared in 1938, with new editions in 1942 and 1944. The purpose was to assemble information regarding mineral resources, production, imports and exports,

relative proportion of the world production of each mineral in every country, dominion and colony of the world, accompanied by very brief descriptions. Apparently, this information was desired at about the time of the first edition. This 4th edition merely attempts to bring the earlier statistical data up to date. Obviously much of the newer developments and later data are not available to the author through direct knowledge or available publications, and as a result the statistical data are incomplete and from 4 to 10 years old.

BOOKS RECEIVED.

ALAN T. BRODERICK.

Reconnaissance of the Geology and Oil Possibilities of Baja California, Mexico. CARL H. BEAL. Pp. 138; pls. 11. Geol. Soc. America Mem. 31, New York, December 1948.

Geology and Origin of South Park, Colorado. J. T. STARK, J. H. JOHNSON, C. H. BEHRE, JR., W. E. POWERS, A. L. HOWLAND, DON B. GOULD AND OTHERS. Pp. 188; pls. 18; figs. 22. Geol. Soc. America Mem. 33, New York, January 1949.

U. S. Bureau of Mines—Washington, D. C.

Vol. 17, No. 12. International Coal Trade. Pp. 54; tbls. 51. **International Petroleum Trade.** Pp. 28; all tables. December 1948. *A monthly inventory of information from U. S. Government Foreign Service offices and other sources that may not otherwise be made available promptly.*

Spec. Supp. No. 26 to Vol. 26, No. 5. Mineral Trade Notes—Copper in Japan. JOHN J. COLLINS. Pp. 72; figs. 34. May 1948. *Comprehensive report including 9 pages on geology. 216 item bibliography.*

The Behavior of Rocks and Rock Masses in Relation to Military Geology. WILMOT R. MCCUTCHEN. Pp. 76; figs. 27; tbls. 4. Colorado School of Mines Quart., Vol. 44, No. 1, Golden, 1949. Price, $1.00.

Illinois State Geological Survey—Urbana, 1948–1949.

Rept. Inv. 137. Viscosity Studies of System CaO-MgO-Al_2O_3-SiO_2: II, CaO-Al_2O_3-SiO_2. J. S. MACHIN AND TIN BOO YEE. Pp. 5; fig. 1; tbl. 1.

Rept. Inv. 138. Colloid Properties of Layer Silicates. W. F. BRADLEY AND R. E. GRIM. Pp. 10; figs. 9.

Rept. Inv. 139. Deep Drilling and Deeper Oil Possibilities in Illinois. L. E. WORKMAN AND ALFRED H. BELL. Pp. 21; figs. 14. *Illustrated by isopach maps and cross sections of formations between St. Peter sandstone and basement rocks.*

Rept. Inv. 141. Fluorspar and Fluorine Chemicals. Part I, Economic Aspects of the Fluorspar Industry. N. T. HAMRICK AND W. H. VOSKUIL. **Part II, Fluorine Chemicals in Industry.** G. C. FINGER AND F. H. REED. Pp. 70; tbls. 21; figs. 7.

Circ. 143. Mineral Resource Research, 1946–1947, by the Illinois State Geological Survey. M. M. LEIGHTON. Pp. 16; numerous photos.

Circ. 148. Airplane Views of Illinois Oil Installations. FREDERICK SQUIRES. Pp. 4; figs. 6. *Airphotos of 5 water or gas injection plants.*

Kansas Geological Survey—Lawrence, 1948.

Bull. 75. Oil and Gas Developments in Kansas During 1947. W. A. VER WIEBE, G. E. ABERNATHY, J. M. JEWETT AND E. K. NIXON. Pp. 230; figs. 51; tbls. 77.

Bull. 76, Part 6. Ground-Water Supplies at Hays, Victoria, Walker, Gorham, and Russell, Kansas. BRUCE F. LATTA. Pp. 73; figs. 8; tbls. 6.

Economic Geology of Some Pegmatites in Topsham, Maine. V. E. SHAININ. Pp. 32; figs. 9. Maine Geol. Survey Bull. 5, Augusta, 1948. *Irregularly-zoned Carboniferous pegmatites emplaced in gneiss by injection and wallrock replacement. Mined for perthite.*

Deposits of the Sillimanite Group of Minerals South of Ennis, Madison County, with Notes on Other Occurrences in Montana. E. WM. HEINRICH. Pp. 22; figs. 6; pl. 1. Montana Bur. Mines and Geol. Misc. Contr. 10, Butte, 1948. *Kyanite followed by sillimanite in and near pegmatites in schists. Reserves and grade not known.*

Ohio Geological Survey—Columbus, 1948.

Rept. Inv. 4. Additional Analyses of Coals of Ohio. ETHEL S. DEAN. Pp. 17; fig. 1.

Rept. Inv. 5. Geology of Newport Township, Washington County, Ohio. WILLIAM H. SMITH. Pp. 7; pls. 2. *Area produces some oil, gas; has some low-grade coal reserves. Rocks are from the Pennsylvania Conemaugh and Monongahela series.*

Seventh Annual Report of the Ohio Water Resources Board for the Year 1948. Pp. 28; figs. 3. Columbus, 1949. *Usual annual report plus interesting section on state legislation concerned with water resource exploitation.*

Ouachita Facies in Central Texas. VIRGIL E. BARNES. Pp. 12; figs. 2. Univ. Texas Bur. of Econ. Geol. Rept. Inv. 2, Austin, 1948. *Study suggests that schists found in Caldwell County bore-holes and previously called Precambrian are Ouachita thrust over Paleozoics. Latter strata may be oil-bearing.*

Commercial Granites and Other Crystalline Rocks of Virginia. EDWARD STEIDTMANN. Pp. 152; pls. 10; figs. 23; tbls. 28. Virginia Geol. Survey Bull. 64, University, 1945.

Bibliography of Seismology No. 3, Items 6734–6857, Jan.–June 1948. W. G. MILNE. Pp. 17. Pub. of Ottawa Dominion Observatory Vol. 14, Dept. Mines and Resources, Ottawa, 1948. *Partly annotated.*

Ontario Department of Mines—Toronto 1948–1949.

Vol. 56, Part II, 1947. Mines of Ontario in 1946. W. O. TOWER ET AL. Pp. 124; numerous tables. *Part of 56th Annual Report.*

Vol. 56, Pt. 8, 1947. Geology of Hearst and McFadden Townships. JAS. E. THOMSON. Pp. 34; photos 8; maps, sections 6; colored geol. map, scale $1'' = 1000'$. *General geology of area containing many showings of weak gold mineralization.*

Prel. Rept. 1948–10. On Echo Township, District of Kenora. H. S. ARMSTRONG. Pp. 7; map 1, scale $2'' = 1$ mi. *General geology of an area containing minor gold, molybdenite and pyrite deposits.*

Prel. Rept. 1948–12. On the Geology of Darling Township and Part of Lavant Township, Lanark County. P. A. PEACH. Pp. 4; map, 1″ = 2 mi. *General geology of an area containing minor graphite, marble and iron deposits.*

Prel. Rept. 1949–1. Progress Report on Drilling to Determine Stratigraphical Succession in Sanborn Township, District of Cochrane. Pp. 5. *0–700 feet, overburden; 700–1000 feet, Onandaga limestone.*

Prel. Rept. 1949–2. The Pleistocene Geology of the Vermilion River System Near Capreol, District of Sudbury, Ontario. V. K. PREST. Pp. 8; map 2″ = 1 mile. *Pre-glacial valley south of Porcupine and Shiningtree lode deposits offers possibilities of undisturbed pre-glacial placers or placers from glacial streams.*

Simon Lake Area, Papineau County. CARL FAESSLER. Pp. 29; figs. 2; pls. 4; map 1, colored, 1″ = 1 mile. Quebec Dept. Mines Geol. Rept. 33, Quebec, 1948. *General geology of area which contains minor deposits of chrysotile, brucite, graphite, ochre, nickel, and copper.*

Australia Bureau of Mineral Resources, Geology and Geophysics—Canberra, 1946–1948.

The Mineral Resources and Industries of the Commonwealth of Australia and the Mandated Territory of New Guinea. H. G. RAGGATT, P. B. NYE AND N. H. FISHER. Pp. 95; graph 1.

Pamph. 3. Radio-Active Mineral Deposits. Pp. 34; colored mineral plates 2. *General information for prospectors.*

Bull. 7. A Study of Australian Diatomites with Special Reference to Their Possible Value as Filter Media. IRENE CRESPIN. Pp. 40; tbls. 2; pls. 6.

Bull. 10. Piezo-Electric Quartz. F. CANAVAN. Pp. 12; pl. 1. *General information on occurrence, mining methods, preparation, etc.*

Bull. 13. Notes on the Occurrence of Piezo-Electric Quartz in Australia with Special Reference to the Kingsgate Field. M. D. GARRETTY. Pp. 21; pls. 3. *Main deposit consists of pipe-shaped cavity fillings in sedimentites near granite contact.*

Each of the following Summary Reports contains from 15 to 45 pages and is illustrated by a geographic map of localities and contains production graphs and tables.

No. 7. Manganese; No. 21. Cadmium; No. 23. Lead; No. 29. Phosphates; No. 32. Cobalt; No. 33. Zinc.

Gisements de Cassitérite de la Région de Kalima, Congo Belge. N. VARLAMOFF. Pp. 44; pls. 12; figs. 11. Liège, 1948. *Apparently follows classic order; magmatic granite intrusion; aplite and pegmatites; tourmalinization, greisenization near cassiterite fissure fillings and replacements.*

La Mine des Kibara, Congo Belge. B. ADERCA. Pp. 14; figs. 6; pls. 10. Liège, 1948. *Nodules and veinlets of tourmaline, beryl and cassiterite in a schist cover over granite. Proposed sequence: tourmalinization followed by an alkaline pneumatolitic-hydrothermal phase carrying stannate radicle. Solution attacked tourmaline, alkalinity was thus reduced and cassiterite deposited.*

Notas Preliminares sobre la Geología del Distrito de Potosí. F. S. Turneaure and T. C. Marvin. Pp. 8; map, scale 1 cm = 1 km. *Areal geology, history, megascopic petrography of formations.*

Great Britain Geological Survey—London, 1948.

Report of the Geological Survey Board for 1947. Pp. 17.

Geology of Southport and Formby. D. A. Wray and F. Wolverson Cope. Pp. 54; figs. 9; pls. 3. *Triassic and Recent strata. Minor oil production.*

Il Contributo della Geofisica alla Ricerca dell' Acqua. Luigi Solaini. Pp. 10; figs. 10. Milan, 1945. *Contributions of geophysics to the search of water.*

Estudos, Notas e Trabalhos do Serviço de Fomento Mineiro, Vol. III, Fasc. 1–2. Pp. 104; numerous maps, figures, photos. Porto, 1947. *4 papers on geology of Portugal. Chromite, platinum, iron, manganese properties described. 1 paper on geophysics (magnetics).*

The Alkaline District of Alno Island. Harry Von Eckermann. Pp. 176; figs. 51; pls. 60. Sveriges Geol. Undersokning No. 36, Stockholm, 1948. *Detailed petrography and petrology.*

Uganda Geological Survey Report for 1944. Pp. 34; tbl. 1. Entebbe, 1948.

SCIENTIFIC NOTES AND NEWS

OSCAR EDWARD MEINZER 1876–1948. A MEMORIAL.

Oscar Edward Meinzer was born on a farm near Davis, Illinois, November 28, 1876, and died in his home in Washington, D. C., June 14, 1948, at the age of 71 years. He is survived by his wife, Alice Crawford Meinzer, and two sons, Robert William, of Berwyn Heights, Maryland, and Roy Crawford, of New Brunswick, New Jersey. Mentally alert and physically active to the last, death came to him without forewarning in the midst of many activities and keen anticipation of the future.

He was one of the six children of William and Mary Julia Meinzer. His grandparents emigrated from Germany to escape the persecution of the Prussian militarists. From them he inherited a strong hatred of war, deep religious convictions, the habits of independent thought, hard work, and deep curiosity concerning his surroundings. His early education was obtained in local schools in Illinois. He was a keen observer. He noted and wondered about the origin of the fossil-packed limestones on his father's farm and determined to learn their history. Even as a boy he recognized the granite boulders in the glacial till as foreign to Illinois and wondered how they reached their resting place. He became interested in ground water through the difficulties encountered with the farm water supply; first with the farm spring, later when the dug well went dry, and finally with the fluctuations of water level in the deep drilled well. When his father gave him $500 to put himself through college, he eagerly took the opportunity to satisfy his curiosity about these and many other things. He enrolled in Beloit Academy in Wisconsin in 1896 and was graduated from Beloit College, Magna Cum Laude, in 1901, having been elected to Phi Beta Kappa in recognition of his excellence in academic work. For two years after graduation he was principal of the public schools at Frankfort, South Dakota. During the next two years he taught science at Lenox College at Hopkinton, Iowa, where he met his future wife, Alice Crawford, and, during the summer, studied geology at the University of Chicago. In the fall of 1905 he enrolled full time in the graduate school at Chicago. The following summer he worked as a geologic aid in the U. S. Geological Survey, and when fall came he married Alice Crawford and returned to his studies. In July 1, 1907, having completed his residence requirements, he accepted appointment as a junior geologist in the Geological Survey and began his life-long study of ground water. His doctor's dissertation, "The occurrence of ground water in the United States, with a discussion of principles," was submitted in 1922. This paper was not only the basis for the award of the degree of Doctor of Philosophy, Magna Cum Laude, but has also served as the principal reference on ground water up to the present. On July 1, 1912, he was made Acting Chief and a year later he was made Chief of the Division of Ground Water, a position which he held until his retirement on November 30, 1946. Meinzer's first assignments on the Geological Survey involved assembling and analyzing field data collected by many men, as in the ground-water investigations in Iowa and in southern Minnesota; and rounding out the field data and preparing the reports

for publication. He later carried out many investigations in various Western and Midwestern States, Cuba, and Hawaii. Early in his professional career he foresaw the importance of ground water in the National economy and concluded that in addition to outlining the areas of ground-water aquifers, their thickness, depth, geologic structure, and physical characteristics, students of ground water must also learn the chemical quality and the quantity of ground water that would be available for beneficial use, and that methods for determining these latter factors must be devised and tested. He insisted that water levels, pumpage, spring discharge, etc., must be measured. He set about systematizing the available knowledge on ground water—much of which had been developed in Europe—and found that the scientific study of ground water had a twofold background; the one prosecuted by geologists as a part of the science of geology; the other by physicists and hydraulic or water-supply engineers as a part of the science of fluid mechanics, but the two lines of investigation had not been effectively integrated. One of his most important contributions to ground-water investigations was that of bringing together geologists and engineers in the development of a comprehensive and systematic branch of science. His "Outline of methods for estimating groundwater supplies," first presented in 1920, but which was revised and published as U. S. Geological Survey Water-Supply Paper 638, in 1932, was the first clear statement of the various methods of estimating "safe yield." He devised many of these methods and encouraged the geologists as well as the engineers to do research in the quantitative field. He established a hydrologic laboratory to study permeability, specific yield, and the laws of fluid mechanics. He was one of the first, if not the first, to recognize the elasticity and compression of artesian aquifers and the significance of these features in relation to the storage of artesian water. He led the way in this country in the study of salt-water encroachment in coastal areas. He outlined and promoted the important work in the analysis of pumping-test results and their application to practical problems. He did much in establishing ground-water geology as an important field in economic geology. One of his last reports was "A report on ground water by the Research Committee of the Society of Economic Geologists," in which he outlined subjects for future research in ground water.

Meinzer was a prodigious worker and a gifted writer. During his professional career he wrote or collaborated in writing about 110 articles and reports. In addition, he critically reviewed the hundreds of reports prepared by members of his division and edited and revised them, or, when necessary, returned them to the author for revision to bring them up to his own high standards. At the time of his death he was preparing a treatise on ground water, a much needed work for which he was preeminently qualified. This work was advanced sufficiently so that it is hoped that his colleagues, with the aid of his extensive and orderly notes, will be able to complete it.

Dr. Meinzer was a charter member of the Society of Economic Geologists; he was Vice-President in 1944 and President in 1945; he also served as a Councillor and was a member of the Executive Committee. He was president of the Geological Society of Washington in 1930–31. He helped to organize the Section of Hydrology of the American Geophysical Union and was its first chairman. At the time of his death he was President of the Union, President of the International Commission on Subterranean Water, and American member of the Executive Committee of the International Association of Scientific Hydrology. He was President of the Washington Academy of Sciences in 1936. He was a fellow of the Geological Society of America and of the American Association for the Ad-

vancement of Science and a member of the National Research Council, the American Water Works Association, and the Pick and Hammer Club of Washington. He was also a member of the Cosmos Club.

Dr. Meinzer was awarded the Bowie Medal of the American Geophysical Union in 1943 for his outstanding contributions to hydrology, and the honorary doctor's degree by Beloit in 1946 on the 100th anniversary of the college.

He was a man of many interests, in farming, in science, politics and religion, in the Boy Scout movement, in which he actively participated, first as a scoutmaster and later as a member of the National Capital Area Council and as a 30-year veteran in the Boy Scouts of America; he taught boys' classes and was an elder in the Sherwood Presbyterian Church (Washington).

Dr. Meinzer's death is a great loss to geology and hydrology, to a host of friends, and to many students of ground-water hydrology who were initiated in this difficult field through his critical but kindly leadership.

A. NELSON SAYRE.

ROBERT B. HALL, geologist with the U. S. Geological Survey, has been transferred from Spread Eagle, Wis., to Grand Junction, Colo.

VICTOR M. LOPEZ is with the Organización Internacional de Investigaciones, Industriales de Venezuela, Caracas, Venezuela.

ANTHONY M. MASTROVICH, formerly with the U. S. Vanadium Corp. at Uravan, Colo., as engineer and geologist, is exploration engineer in the western mining department of the American Smelting and Refining Co., at Salt Lake City.

A. D. BAIN, formerly of Nigeria, Africa, has been appointed assistant chief geologist to the State Department of Mines, Victoria, Australia.

PAUL A. BUNDY, mining engineer and geologist of Nevada City, Calif., is now located on the Isle of Pines, Cuba, where he is carrying out extensive examination and exploration work for Cuban and Canadian mining interests.

PHILIP GUILD of the U. S. Geological Survey, who has spent two years in studying the manganese deposits of Minas Gerais in Brazil, recently took part in the II Geological Meeting, sponsored by the Brazilian Society of Geology at Sao Paulo.

DONALD H. MCLAUGHLIN, of Homestake Mining Company, has moved his office to 100 Bush Street, 26th Floor, San Francisco 4, Calif.

BEHRE, DOLBEAR AND COMPANY, 11 Broadway, New York, N. Y., have been appointed by the Union of Burma as General Consultants and Technical Advisers on Minerals. The Government is planning an expansion of the mineral industries in Burma which, aside from petroleum, include gold, silver, lead, tungsten, tin, copper, nickel, antimony, iron, coal, clay, as well as rubies, sapphires, jade and amber. Behre, Dolbear and Co. would like to hear from engineers and geologists who have had experience in Burma.

A joint Annual Meeting of the American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists and the Society of Exploration Geophysicists took place in St. Louis, Missouri, on March 14 to 17. The Missouri and Illinois Geological Surveys had organized a geological field trip to Cape Girardeau.

The Fourth Empire Mining and Metallurgical Congress, convened by the Empire Council of Mining and Metallurgical Institutions, will be held in Great Britain

from July 9 to 23, 1949, under the presidency of Sir Henry T. Tizard. The chief object of the Congress is to afford an opportunity for scientists, engineers and others concerned with the mining and metallurgical industries to meet and discuss technical progress and problems, including the development of the mineral resources of the Commonwealth.

J. E. L. EVANS delivered two lectures dealing with the Geology of Northern Labrador at Queen's University, Kingston, on February 24 and 25.

COURTNEY E. CLEVELAND, for many years exploration engineer and geologist for the Bralorne Mines Ltd. of Vancouver, B. C., has joined the geological staff of the Barnsdale Oil Company, 735 8th Avenue West, Calgary, Alberta.

FEDERICO E. AHLFELD, formerly chief of the Mining Department, Institute of Geology and Mining, Jujuy, Argentina, was engaged as consulting mining engineer and geologist by the Empresa Minera Unificada S. A. with headquarters in La Paz, Bolivia.

The Economic Cooperation Administration has undertaken to finance in part the employment of approximately 25 geologists, petrographers, and chemist-assayers by various British Colonial Surveys. The objective is to aid in the development of the mineral resources of the Colonies at a time when British technologists, because of the interruption of technical training during the war, are in short supply. The measure is a temporary one—of three years duration—when it is expected that British trained technologists will again be available.

The basic qualifications for any of these positions is a bachelor's degree in geology with grades comparable to an "honours degree" from a British university and 5 years of professional field experience. It is hoped that some men with 10 years experience will be available. The age range is expected to lie between 28 and 40 years. The colonies to which assignments will be made are Nigeria, Gold Coast, Sierra Leone, Kenya, Tanganyika, Uganda, Nyasaland, North Borneo and Sarawak, and British Guiana. The specialized technical personnel required are 2 petrologists, 2 chemist-assayers, 17 field geologists, and 4 ground water geologists. The field geologists will principally be engaged in areal mapping.

The men will be employed by the U. S. Geological Survey as at the Professional Grades 6, 7 and 8, depending on their qualifications. It is expected that 75 to 80 percent of their salary will be paid in dollars and the balance in sterling. Further information can be obtained from the Chief, Alaskan and Foreign Geology Branch, U. S. Geological Survey, Washington 25, D. C.

WALTER L. MAXSON, vice president of the Oliver Iron Mining Co., Duluth, Minn., has been appointed to the Atomic Energy Commission's Advisory Committee on Raw Materials.

COLIN OSBORNE HUTTON has been advanced to Professor of Mineral Sciences at Stanford University, Calif.

The Field Conference of Pennsylvania Geologists will hold its annual meeting May 27–29 at Lancaster, Pennsylvania. The Department of Geology of Franklin and Marshall College will be host. The major feature of this year's field excursion will be a trip through Southern Lancaster County to study the Martic overthrust problems under the leadership of Professor Ernst Cloos, of the Johns Hopkins University. Other field excursions will include the old Wood chrome mine, Gap nickel mine, other old metal mines, and the flood plain of the Susquehanna River. For further details, address Dr. Richard M. Foose, Department of Geology, Franklin and Marshall College, Lancaster, Pennsylvania.

ALFRED L. ANDERSON, Professor of Economic Geology, Cornell University, Ithaca, New York, is spending his Sabbatical leave of absence the second term visiting mining camps in the southwestern states.

WESTON BOURRET has changed his residence from Scarsdale, N. Y., to 1107 San Pasqual St., Pasadena 5, Calif. He is with the exploration department of the Kennecott Copper Corporation.

DOUGLAS C. BROCKIE is a geologist for Eagle-Picher de Mexico, and can be reached in care of Minas de Iguala, Parral, Chihuahua, Mexico.

JOHN J. COLLINS, mining geologist, U. S. Geological Survey, Washington, D. C., returned to the States in February after completing assignments with the Corps of Engineers in the Western Pacific. His major activity was a study of the Japanese copper resources, production, and trade for the Natural Resources Section, GHQ, SCAP. Other assignments covered the mineral resources of the Yap Islands, the Fukui earthquake, coal production in Japan in 1945, and military geology studies of Japan and Okinawa.

ALFRED L. RANSOME, who was supervising engineer with the Bureau of Mines' Metal Economics Branch in San Francisco, is now with the Bureau's Alaska branch in the same capacity. His address is now P. O. Box 2628, Juneau.